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DEFECTS OF IMPORTANCE IN THE SPECIFICATION
OF REINFORCED PLASTICS PRODUCTS

23 MARCH 1953



U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

DEFECTS OF IMPORTANCE IN THE SPECIFICATION
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ABSTRACT: Many military specifications exist for the purchase of laminated plastics materials for government use. These documents adequately specify physical properties at ambient conditions but leave to the procuring agency the details as to what is to be considered acceptable workmanship in quality in regard to the classification of defects. This report supplements those specifications by picturing common flaws and defects and by discussing each and its possible effect on laminated items under various conditions of service usage as encountered with naval ordnance. Thus the procuring agency is provided with a basis of specifying workmanship and quality in a more exact fashion. Still remaining to be collected, for full and complete specification purposes, is mechanical and chemical property data on the materials themselves under the many environmental conditions common to the military service.

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NAVORD Report 2797 presents a discussion of the visual characteristics and the various flaws to be found in glass reinforced plastics. It is intended that the illustrations and the accompanying discussion be used as guides and as points of reference by those who must specify the quality of plastics for use in naval ordnance and by those who must determine if materials meet manufacturing specifications. This report supplements NAVORD Report 2669 on the strength properties of laminated materials and also the various applicable government specifications. The work was originated at the request of the Naval Ordnance Test Station, Inyokern, California, and was concluded as authorized by task NOL-Re6a-268-18-53.

EDWARD L. WOODYARD
Captain, USN
Commander

D. S. MUZZEY, Jr.
By direction

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REFERENCES

- (a) Military Specification MIL-R-7575 (USAF) "Resin, Low Pressure Laminating" of 3 Apr 1952
- (b) Military Specification MIL-P-8013 (USAF) "Plastic Materials; Glass Fabric Base, Low Pressure Laminated Aircraft Structural" of 19 Sep 1952
- (c) NAVORD Report 2669, "Evaluation of Glass Fabric Reinforced Plastics Laminates" of 30 Jan 1953
- (d) Battelle Memorial Institute Report, "Nondestructive Testing of Plastic-Glass Laminates" of 31 Oct 1952. Contract No. NObS-55548, Index No. NS-034-045, Sub-Task 21 to Bureau of Ships, United States Navy
- (e) Forest Products Laboratory Report 1814, "Effects of Defects on the Tensile and Compression Properties of a Glass-Fabric-Base Plastic Laminate" of Jun 1950

DEFECTS OF IMPORTANCE IN THE SPECIFICATION
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INTRODUCTION

1. Procurement for government usage requires material and process specifications which will assure that products with given properties and with limited variations in these properties will be obtained. For reinforced plastics, several such specifications exist. They each cover a specific class or group and are usable only within their stated limitations. A specification selection is, therefore, necessary and must be based upon the development work which determined the materials for the particular application in question. The broad coverage of these specifications runs from reinforcements and resins to specific combinations of these two, i.e. "Plastic-Material, Laminated, Thermosetting, Sheets, Paper-Base, Phenolic-Resin" and "Plastic-Material, Laminated Thermosetting, Sheets, Glass-Cloth Melamine-Resin". The purpose of this report is to deal only with those specifications which exist for the "polyester" type resins (reference (a)) and the "polyester"-glass cloth-glass mat laminated plastics (reference (b)). Such laminates are finding extensive use in the ordnance field and their description and specification has become of prime importance.

2. References (a) and (b) adequately cover the specifications of the various mechanical and electrical properties of the resins and the laminated materials. Minimum and maximum values are listed which serve as a quality control in the purchase of these plastics and, in addition, provision is made for the mutual specification of the manufacturing processes between the procurement agency and the contractor. Thus the properties of a molded laminated shape may be indirectly set. To meet the requirements of this specification it is, of course, necessary for the development engineer to determine which reinforcement and process must be used for attaining the required strengths and properties for a particular design.

3. After properties and process are specified, allowance must then be made for flaws which result in reduced properties of the laminates (reference (a)). This is covered in part under the "Workmanship" clause of reference (b). Various flaws are listed and it is noted that the allowable flaws in a part should be agreed upon between the procurement agency and the contractor in the approved process specification.

However, this part of reference (b) is still not sufficiently specific for many applications. Further definition of these flaws, a method of their determination and inspection in a translucent laminate and a table or tables of their relative importance in different types of applications is needed.

4. Some work on the detection of flaws (reference (d)) has been done and ultrasonic, radiographic, dielectric, electrified-particle penetration, dye penetration, and light have been considered as inspection means. The results of this work indicated that no satisfactory commercially available test apparatus now exists and that development of a method is necessary. An effort has been made at NOL to classify flaws by the light method (visual) and of picturing examples photographically. A set of photographs will furnish standards by which to establish the allowable flaws and also will serve as a guide to the Naval inspector in his acceptance of translucent plastic laminated pieces.

DISCUSSION OF FLAWS

5. The primary flaws to be found in laminate materials are:

- a. air and gas bubbles
- b. crazing
- c. resin pools and wrinkles
- d. poor wetting
- e. delaminations
- f. patches
- g. surface flaws

It is these flaws with which this report is concerned. Other flaws listed in reference (b) such as surface tackiness, uncured areas, and gaps are not covered because their description is difficult with photographs and they can easily be determined by an inspector.

6. The precise effects which different flaws will have on a given structure is difficult if not impossible to determine without actual prototype or design model tests. Some laboratory work on panels (reference (e)) indicates that decided strength reductions may be expected in tensile and compression properties due to flaws such as high and low resin content, wrinkles, and butt and lap joints in the plies of the reinforcement. These decreases may amount to as much as 53% for ultimate tensile strength and 27% for ultimate compression strength. The modulus values for either of these tests are not decreased more than 15%, however. With the possible detrimental effects which may arise from the inclusion of flaws it obviously becomes an important function of design, not only to provide the basic strength in a part as based on ideal laminate data, but also to allow for the elimination of flaws in the reinforcement lay up procedures and

in the actual molding processes. Where flaws can not be precluded, allowance must be made for more material bulk to make up the expected differences in strength. Safety factors must be high to cover the possibility of flaws. In turn these safety factors will work against the strength deterioration of the material due to environmental conditions.

7. A discussion of the flaws to be found in laminate materials follows. The comments under each type of flaw are based on this laboratory's experience in the development of underwater ordnance constructed in part or primarily of plastics.

a. Air and Gas Bubbles

8. Air or gas bubbles in a laminate may constitute a very serious flaw for certain applications. Laminates with but very slight amounts or no visible bubbles are often termed "void free" and are the optimum quality laminates pictured in Figures 1 and 2 of this report. The primary question to be answered is how much air and gas bubbles can be tolerated considering the end use. If simple stress is the only factor involved then these bubbles are of importance only as a large or excessive amount of them indicate poor quality and workmanship on the part of the fabricator. Bubbles will appear on the surface as in Figures 5 and 6 or internally as in Figures 3 and 8. Surface bubbles are serious as their presence makes it difficult if not impossible to use many of the standard methods of gasket sealing to the laminate surface. Internal bubbles when numerous and bunched, Figures 4 - 8 indicate areas where the laminate will have a high rate of moisture or gas permeability. In fact they may form actual channels through which water can be forced under low pressures. Laminates with minor or slight amounts of bubbles, Figure 3 and 4, apparently suffer no decrease in their physical properties.

9. Insufficient resin in a laminate produces voids between the weave of the cloth (Figure 9). This is an extension of the idea of excessive air and gas bubbles and is the case where the cloth is well wetted but the resultant laminate simply does not have sufficient resin in it to fill out the voids between plies and in the weave of the fabric. Laboratory data show that laminates of this character, besides being porous, are low in their physical properties (reference (c)).

b. Crazing

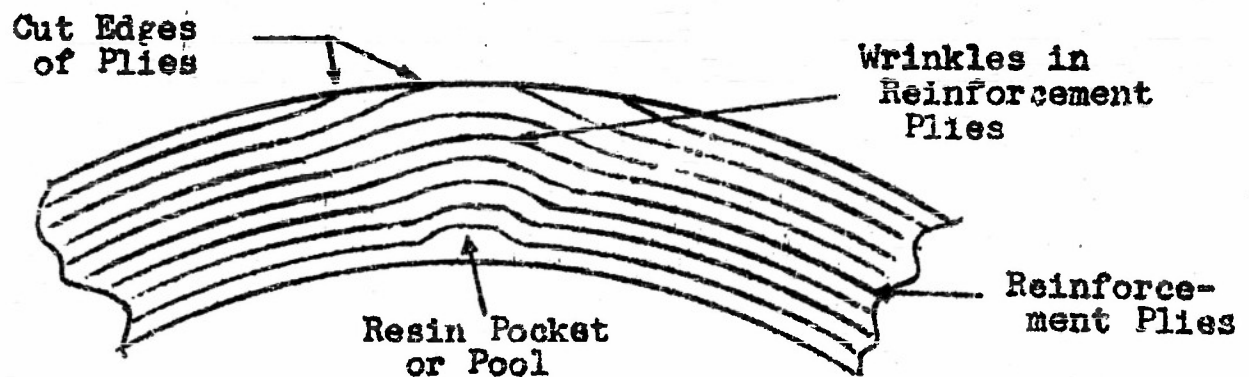
10. Crazing, an indication of localized bond cleavage between resin and reinforcement is a very common occurrence in a laminate. In its minor conditions, it tends to give a hazy translucent appearance to the laminate, see Figures 10 and 11. Small white specks or dashes can be seen which occur at the points of maximum bend in the yarn of the reinforcement fabric. In a more severe condition crazing occurs rather heavily along a given ply following a defined pattern and appearing very much like a water mark,

figures 12 - 15. This type of flaw in its severe condition indicates that something was wrong with the reinforcement and means a product with degraded properties having very poor resistance to outdoor weathering or any form of humidity cycling. Oil or grease on the fabric or a finish not evenly or effectively applied are factors which may cause the occurrence of this flaw. In one condition, crazing may cause the entire laminate structure to be "white" and lacking in translucency. See Figures 15 and 16. This same condition may be brought about by a high heat cure of a laminate which has not been properly wetted out prior to the cure or which was fabricated under excessive humidity conditions.

11. The presence of crazing is probably not too serious where good properties and their maintenance is not a prime consideration. In severe structural applications and in special cases such as with the use of silane finishes to give greatly improved wet strengths to glass fabric laminates, crazing is of considerable importance. Here crazing indicates that the laminate is very susceptible to moisture and that the expected properties can not be attained and maintained when there is temperature and humidity cycling involved in the application.

c. Resin Pools and Wrinkles

12. Resin pools or pockets and wrinkles in the reinforcement tend to occur simultaneously. If the resin pocket is of any size, the resin will become badly cracked due to initial shrinkage on cure, to thermal expansion and contraction, to aging, or to rough handling. Such a defect can present a serious strength decrease when the situation is such as that shown in Figure 18. If this condition is viewed in cross section it appears thus:



At the point of the resin pool, several plies have been removed from the opposite side of the laminate in maintaining the correct thickness to the curved piece, Figure 19. Therefore, the piece is much weaker at this point.

13. If the wrinkle is of a minor nature such as that shown in Figure 20, there will be no resin pool and no significant reduction in strength will be noticed. Sharp wrinkles such as that shown in Figure 21 may significantly decrease the strength of a part as evidenced by the data of reference (e).

d. Poor Wetting

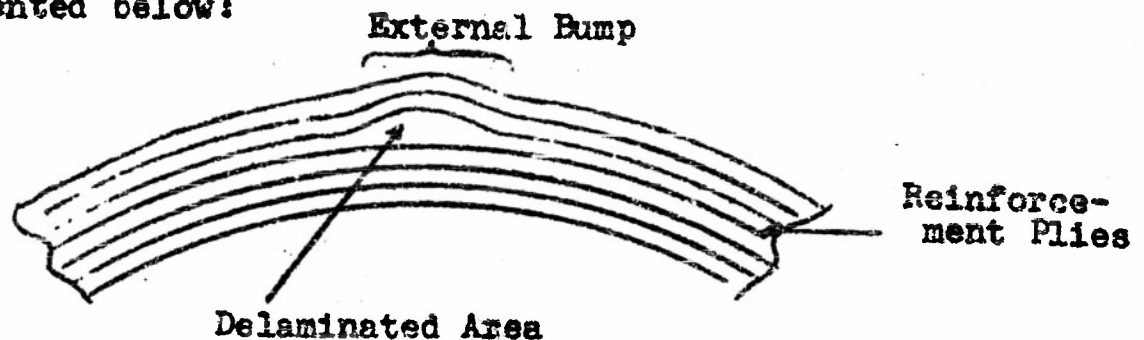
14. Poor wetting may be of two types, first, that indicating that only the outer plies of reinforcement are not properly wetted but that the remainder of the laminate has its proper translucent character (Figures 22 and 23), and second, that which indicates that the bulk of the plies in the laminate are not wetted and that the laminate is starved of resin (Figures 24 and 25). Such a flaw may involve the entire laminate or may consist of poorly wetted spots. If only poor surface wetting of the first type or if small areas are involved, these usually may be corrected by painting with resin and by patches. Nothing can be done to correct the worst condition, however. Figure 23 shows poor surface wetting, by reflected light. This surface has a "soft" feel similar to that of the original fabric as contrasted with a smooth hard feel to the surface of a properly wetted laminate. Such a surface is very susceptible to abrasion as well as moisture pickup.

15. The above examples will most usually be an indication of poor molding techniques. To preclude it, proper care must be taken to insure complete wetting of the reinforcement before cure of the resin.

16. A common practice with reinforced plastics is to use plies of glass mat in conjunction with glass cloth. With such a technique it is very possible to develop the condition in which the cloth wets out but the wetting of the mat is very spotty. Figures 26 - 28 are examples of this flaw. Here again large areas of poor wetting indicate poor molding practices and the product will be inferior for many applications.

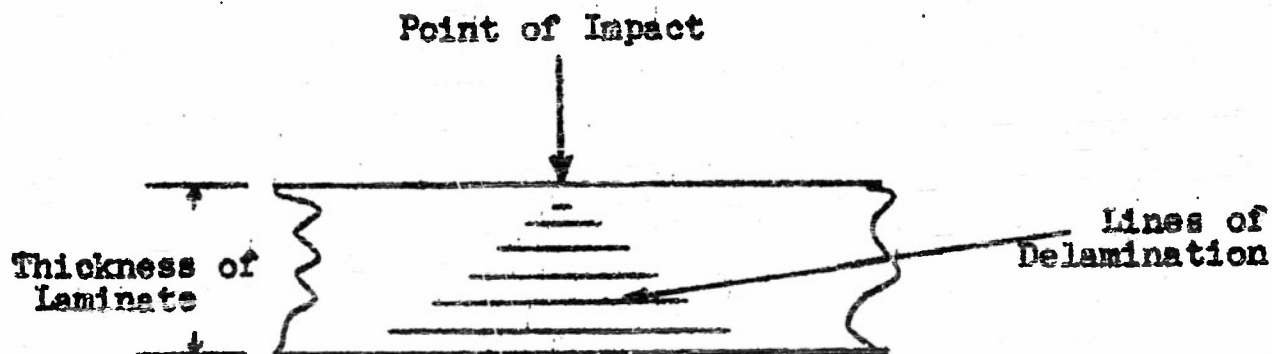
e. Delaminations

17. The production of convolutely rolled glass-fabric reinforced tubes of heavy wall thickness leads to the problem of interply delaminations. See Figures 29 and 30. When the wall thickness-to-inside diameter ratio increases beyond a certain limit these delaminations occur. The condition within the wall of the tube is as represented below:

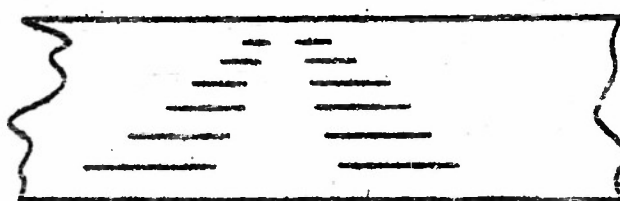


This same general flaw may also be noted on low-pressure molded panels of great thickness where insufficient molding pressure has been used. Obviously there are strength decreases when such a laminate structure is stressed.

18. Delaminations caused by concentrated impact blows on the surface of laminates constitute a very severe form of damage. Particularly where high-pressure water exposure is to be expected and/or if the delamination spot occurs at a point of maximum stress in the piece. This type of flaw indicates a destruction of the bonds between individual reinforcement plies in the laminate. The pattern of delamination to be expected, if the laminate were sectioned for examination, is:

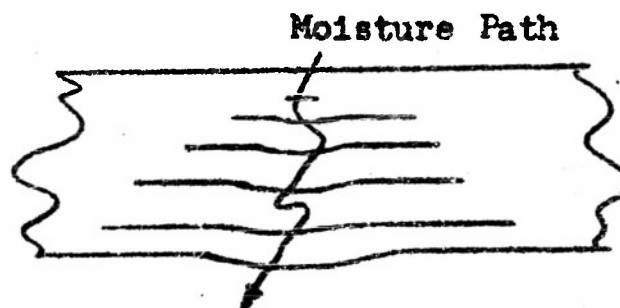


Under certain conditions this pattern may be as follows:



Either case is equally serious. See Figures 31 and 32.

19. Under conditions of hydrostatic pressure on the side of the peak of the delamination cone the laminations at the base of the cone will bulge and moisture channels through the laminate will readily open up.



20. Visual inspection of an unpigmented, unpainted, translucent laminate presents no problem. The flaw will appear as those in Figure 31 when viewed by transmitted light.

f. Patches

21. Patches, Figure 33, may be present in a laminated piece because of a basic flaw in the original molding which was considered repairable. Such flaws which may be so repaired are porous areas, resin pockets, resin starved areas, large surface pits, poorly wetted areas, etc. They may mean that the original material may have been dug out to some depth and then the resulting hole filled with pieces of reinforcement, wetted with resin, and cured in place. It has been reported that up to 85% of the original strength of the material can be developed with a major patching operation. However, in critical applications, patches are not desirable because of their potential weakness.

g. Surface Flaws

22. "Rough" surfaces may occur because the release coat on the mold was not properly cured before molding of the piece. Styrene in the molding resin then attacks the release coat and "lifts" it so that the surface of the molded piece becomes rough at these points. This flaw, Figure 34, has no effect on the properties of the piece as such, except where a seal may be required.

23. Scratches, Figure 34, may also occur and are the result of rough or careless handling. They do nothing more than mar the appearance of the part unless they are deep enough to cut down into the plies of the reinforcement material in which case they detract from the strength of the piece by reducing the effective load-bearing area and by acting as stress-raisers, thus decreasing resistance to impact loadings.

24. Pits may also occur in the surface of laminates. Small ones indicate a poor mold surface or the presence of foreign matter on the mold surface and may generally be considered as of no consequence. See Figure 35. Large pits, however, are indicative of improper molding conditions. See Figure 36. They develop as a result of not having enough material, in effect, at that point of the pit. This flaw is precluded in some moldings by incorporating a layer of glass mat between the glass fabric plies. The mat tends to be resilient and adjusts to variations in the cavity space in a mold and between differences in the quantity of fabric at any point in a lay-up.

25. Grooves occur in the surfaces of laminates and are the result of wrinkles in the cellophane covers put over the laminates to keep air from the resin during cure and for use as a confining bag for the excess resin. See Figure 37. If bag molding techniques are used to produce a piece, there may be fairly large surface

grooves and wrinkles which occur because of folds in the rubber bag and because of different amounts of reinforcement at different points in the lay-up. The same viewpoint of these flaws may be taken as in the case of wrinkles.

CONCLUSIONS AND RECOMMENDATIONS

26. Military specifications MIL-R-7575 and MIL-P-8013 are excellent standards on which to base the procurement of glass fabric reinforced plastic ordnance parts. All the necessary mechanisms are presented for the specification of the materials and of the production processes for the desired piece. The best possible specification of an item, however, still depends upon the data and information as to workable material combinations and processes gathered during the development phases. The above specifications lack primarily in one respect; a satisfactory method of evaluating quality of the materials in regard to inclusion of flaws. A step in the direction of eliminating this lack by photographically classifying these flaws is presented in this report.

27. Even though it is possible to specify materials for military use, the above does not insure that all the environmental conditions, such as temperature cycling, long term storage, long term water immersion, and shock loading, will be met. Further data are still needed to assure that the materials selected will be capable of fulfilling these aspects of any application. Meanwhile the existing data and specifications are adequate for the procurement of prototype and design units but their full satisfactory service performance must still be assumed.

28. It is emphasized that the specifications discussed herein are limited to polyester resin-glass reinforced laminates having a translucent nature. This does not mean that low pressure phenolic resin laminates could not be included. They will meet the physical requirements but will present some difficulties in making an inspection for flaws because they have no degree of translucency whatsoever. Although the foregoing discussions have been primarily in terms of glass fabric laminates, glass mat laminates are also included in reference (b) and the same flaws pictured in this report are common to them. Mat panels are, therefore, also to be considered under the above.

29. Appendix I, Types of Defects, and Appendix II, Allowable Flaws Under Typical Service Conditions are submitted as two criteria for the determination of the importance of various flaws to be found in laminates. The exact importance to be attached to each, however, still lies with the development engineer as he takes into consideration all aspects of his particular application. At this time the consideration of these flaws can be fitted into the Classification of Defects as set forth in MIL-STD-105A and other applicable instructions.

30. In considering plastic parts for a military use, it is most expedient to carry out a development phase on the application. This is a must in many instances as there is little precedent for proper design in specialized military applications and at the same time the actual loadings, shock and static, can only be estimated. Therefore, thorough testing of various designs in prototype form is necessary to establish the feasibility of the application. The development work, assuming that the application is feasible, can be expected to establish:

- a. proper design
- b. proper materials
- c. a process of manufacture (not necessarily the final one)
- d. a classification of defects based upon the prototype tests.

31. With the development work as background, the following procedure for the preparation of specifications for procurement purposes is recommended:

- a. Use MIL-R-7575 and MIL-P-8013 for specification of the materials and the manufacturing processes.
- b. Use the illustrations of this report as standards for establishing the quality desired by the designer and as a basis of comparison for the use of the inspector.
- c. Establish pertinent tests by which the finished item may be partially or fully evaluated.

APPENDIX I

TYPES OF DEFECTS

I Defects Which Would Cause Failures Whenever Present

- a. Delamination from impact blow
- b. Interply delaminations
- c. Excessive amounts of bubbles
- d. Large starved areas
- e. Large wrinkles and resin pools
- f. Large uncured areas

II Defects Which Might Cause Failures if Present

- a. Poor wetting of interply mat layers
- b. Poor surface wetting
- c. Major crazing
- d. Major amount of bubbles, interior and surface
- e. Patches
- f. Gaps

III Defects of Minor Importance

- a. Minor amounts of bubbles
- b. Minor to slight crazing
- c. Surface finish, wrinkles, pits (small), scratches (small) tackiness

APPENDIX II

ALLOWABLE FLAWS UNDER TYPICAL
SERVICE CONDITIONS

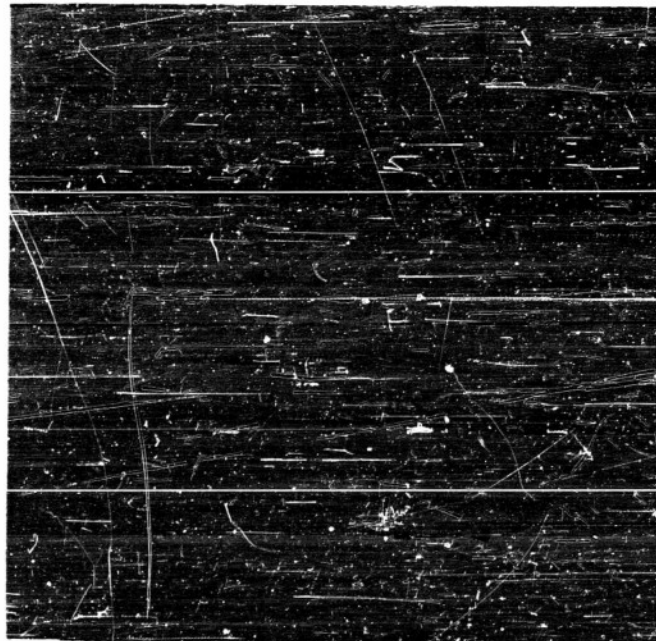
- I Where low water absorption, low water permeability, and high strength are important, a laminate should be characterized by:
- a. Minor amounts of bubbles or none
 - b. No starved areas
 - c. No delaminations, interply or other
 - d. No major crazing
 - e. No major reinforcement wrinkles or folds
 - f. No resin pools
 - g. No major surface pits
 - h. Smooth unabraided surface
 - i. No poorly wetted area
 - j. No patches
 - k. No surface scratches or indentations
- II For a purely high strength application, the following flaws might be tolerated:
- a. Minor amounts of bubbles or less at critical stress areas
 - b. No delaminations, interply or other
 - c. Smooth unabraided surface, no major surface pitting
 - d. No major reinforcement wrinkles or folds at critical stress areas
 - e. No resin pools at critical stress areas
 - f. No major crazing
 - g. No starved areas at critical stress areas
 - h. Limited poorly wetted areas
 - i. No patches at critical stress areas

APPENDIX II (cont'd)

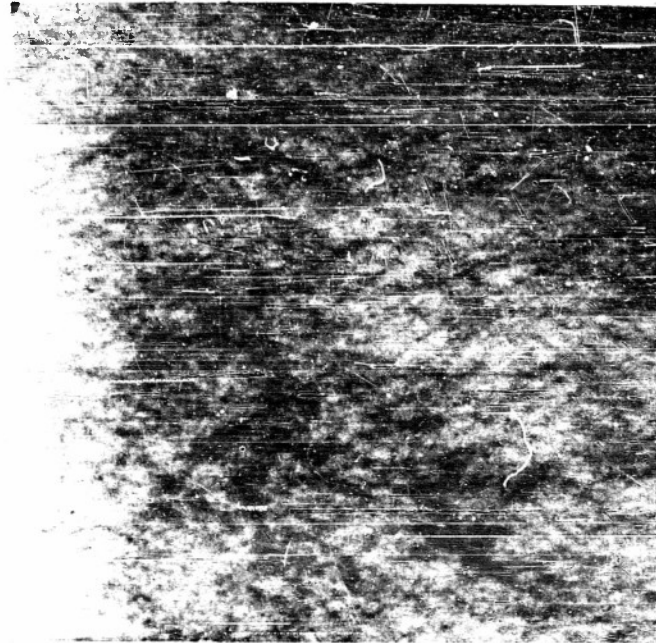
III For general use, having no special property requirements the laminate may be characterized by:

- a. Major amount of bubbles or less
- b. Surface not extremely smooth or free from pits, abrasions or cuts and dents
- c. Some delaminations (small size) present
- d. Wrinkles and folds
- e. Resin pools
- f. Crazeing
- g. Limited starved areas
- h. Some poorly wetted areas
- i. Patches

PHOTO BY REFLECTED LIGHT



GLASS CLOTH LAMINATE



GLASS MAT LAMINATE

FIG. 1 OPTIMUM QUALITY LAMINATES

PHOTO BY TRANSMITTED LIGHT



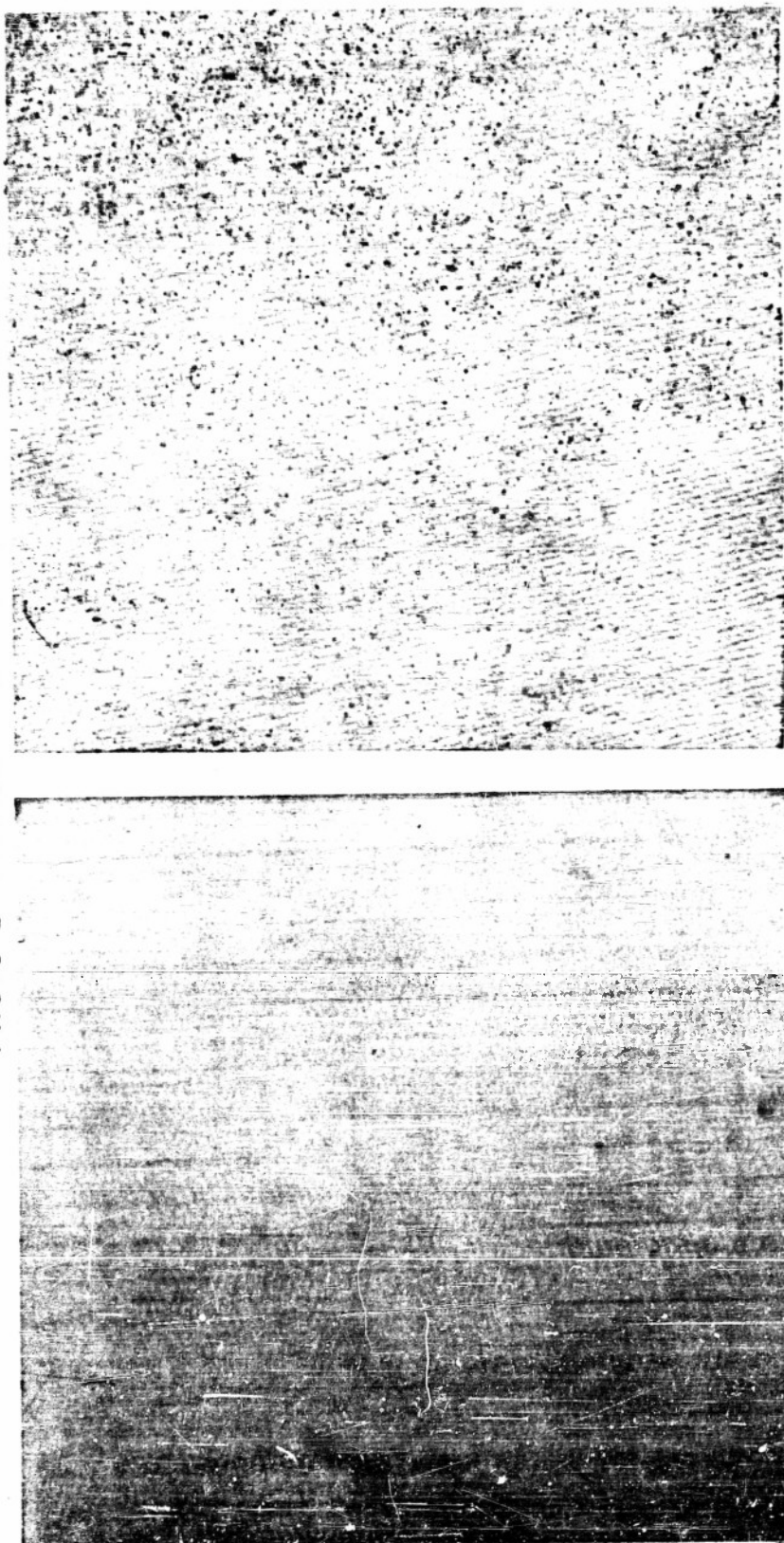
0.150 THICK LAMINATE

0.175 THICK LAMINATE

0.475 THICK LAMINATE

FIG. 2 TRANSLUCENCY VARIATION OF LAMINATES WITH THICKNESS

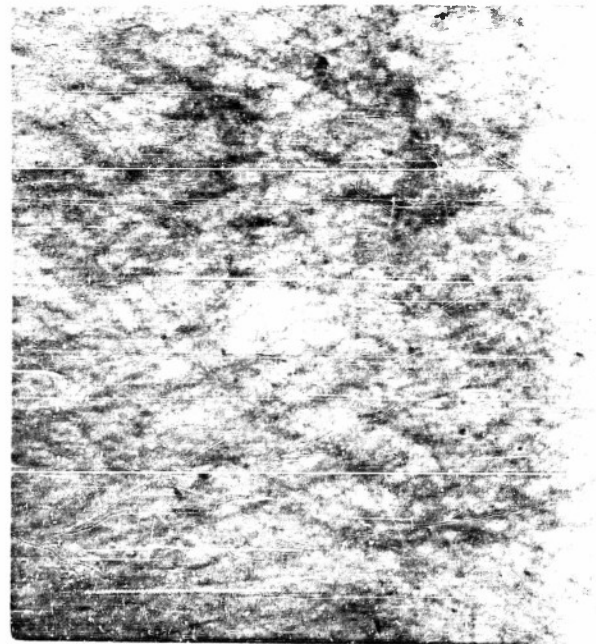
PHOTO BY TRANSMITTED LIGHT



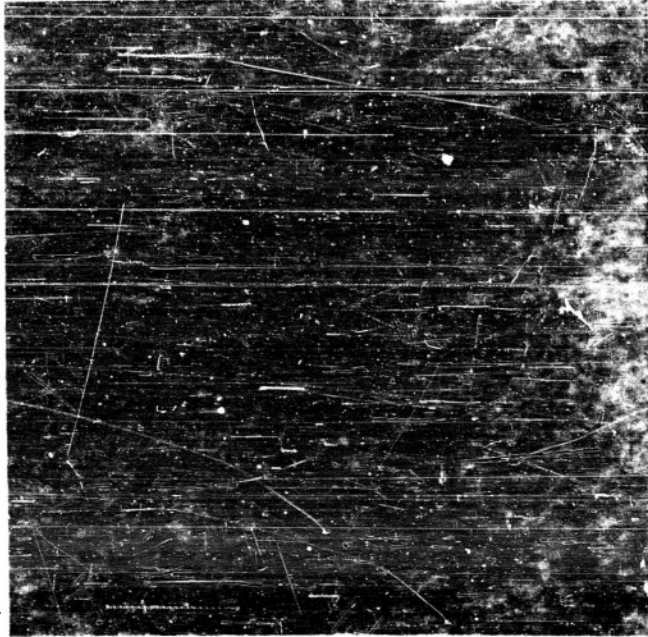
OPTIMUM QUALITY LAMINATE MINOR AMOUNTS OF AIR AND GAS BUBBLES

FIG. 3 MINOR AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY MAT LAMINATE



MINOR AMOUNTS OF AIR AND GAS
BUBBLES IN MAT LAMINATE

FIG. 4 MINOR AMOUNT OF AIR AND GAS BUBBLES

PHOTO BY TRANSMITTED LIGHT

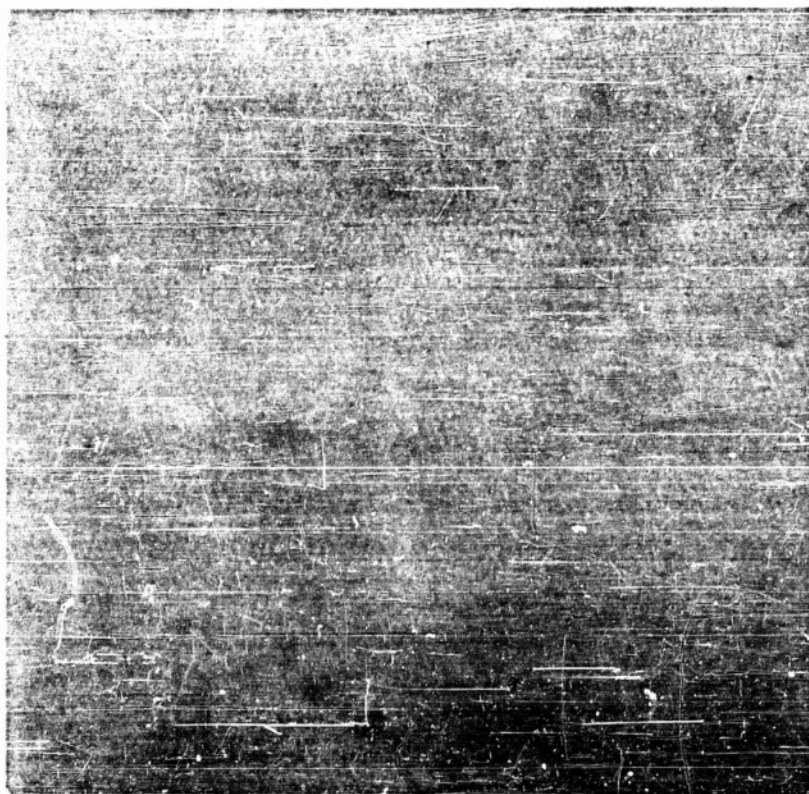


OPTIMUM QUALITY LAMINATE

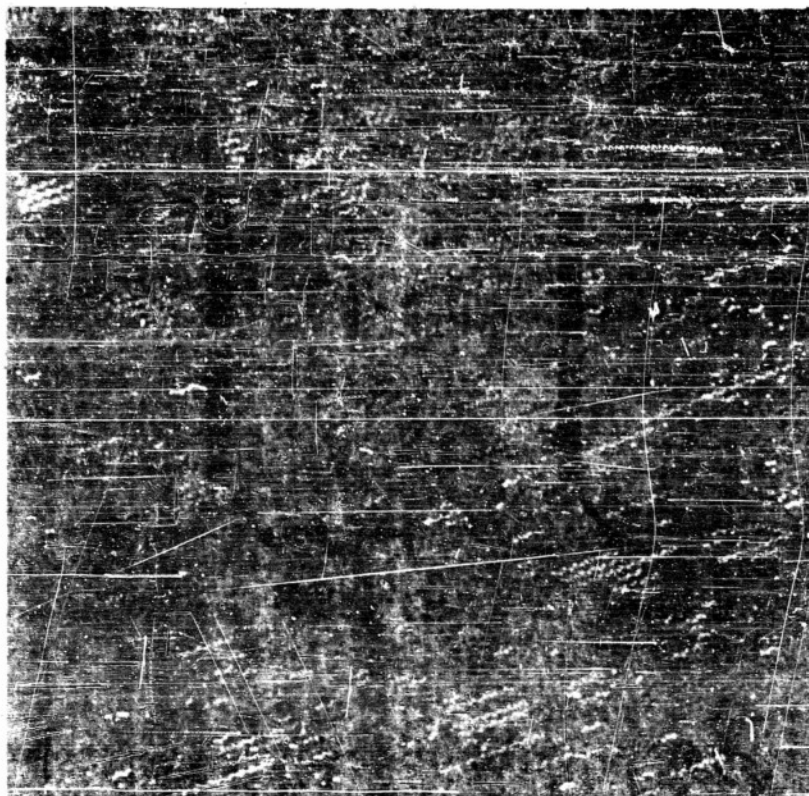
MAJOR AMOUNT OF AIR AND GAS BUBBLES

FIG. 5 MAJOR AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE



MAJOR AMOUNT OF AIR AND GAS BUBBLES

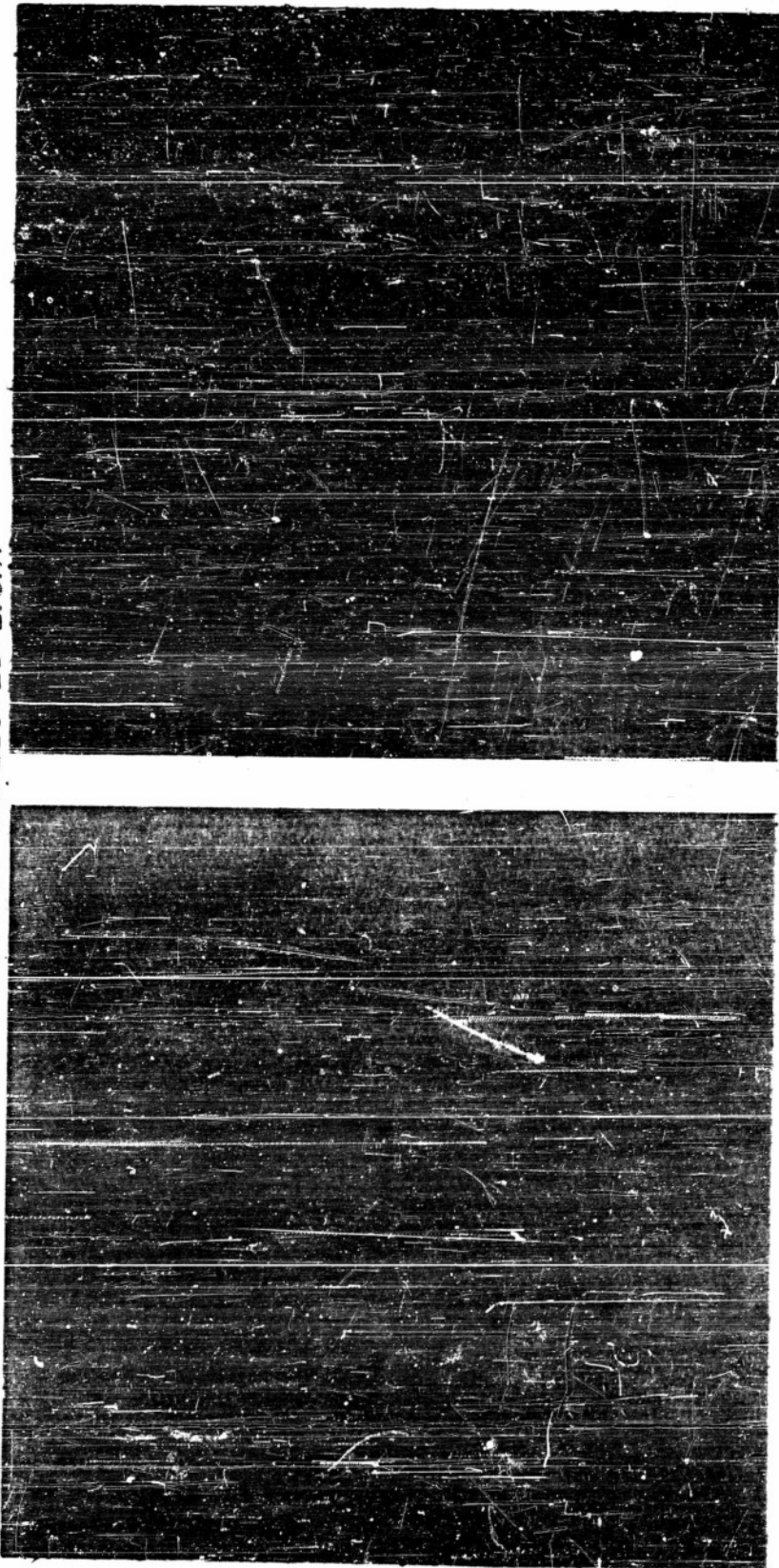
FIG. 6 MAJOR AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES
FIG.7 EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES
FIG. 8 EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

NAVORD REPORT 2797

PHOTO BY REFLECTED LIGHT

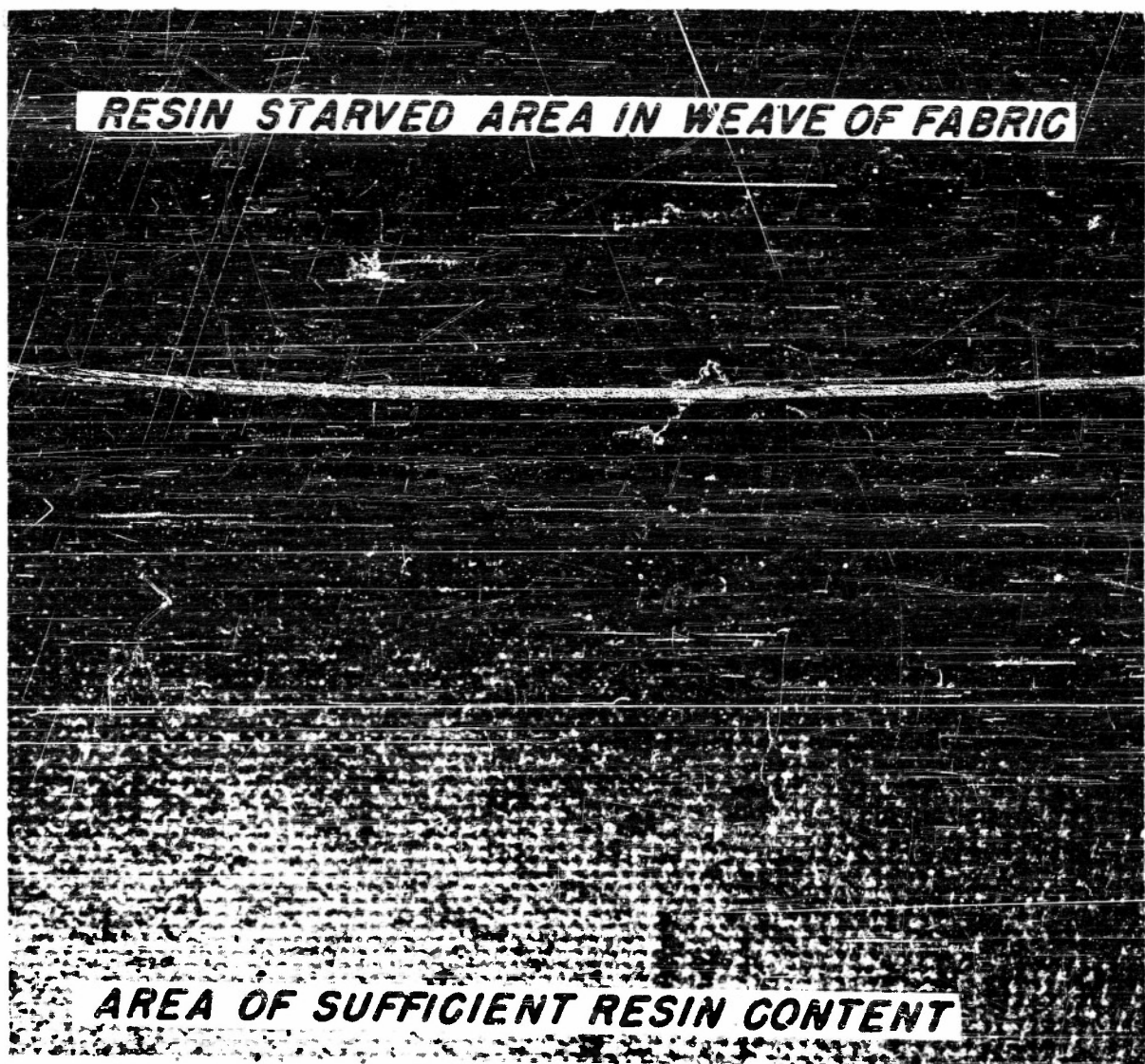
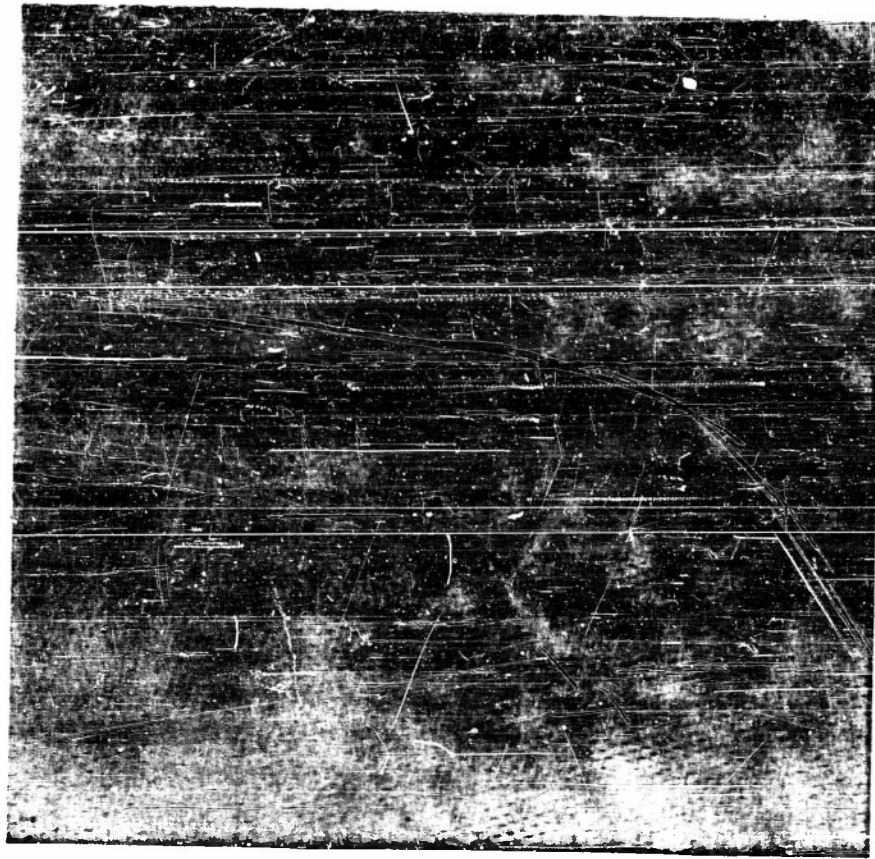


FIG.9 RESIN STARVED LAMINATES

PHOTO BY TRANSMITTED LIGHT



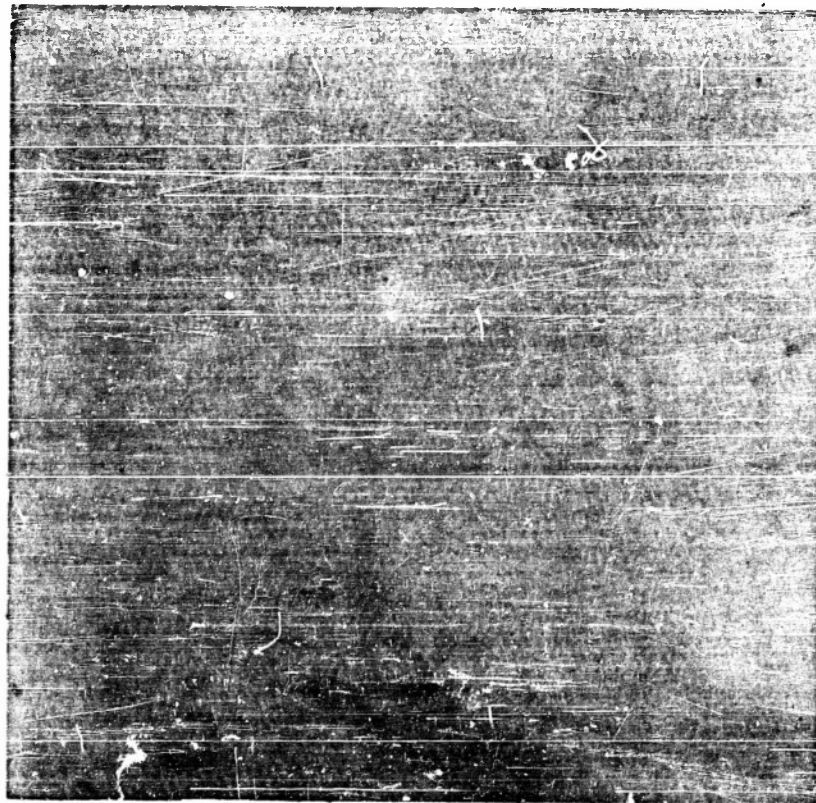
OPTIMUM QUALITY LAMINATE



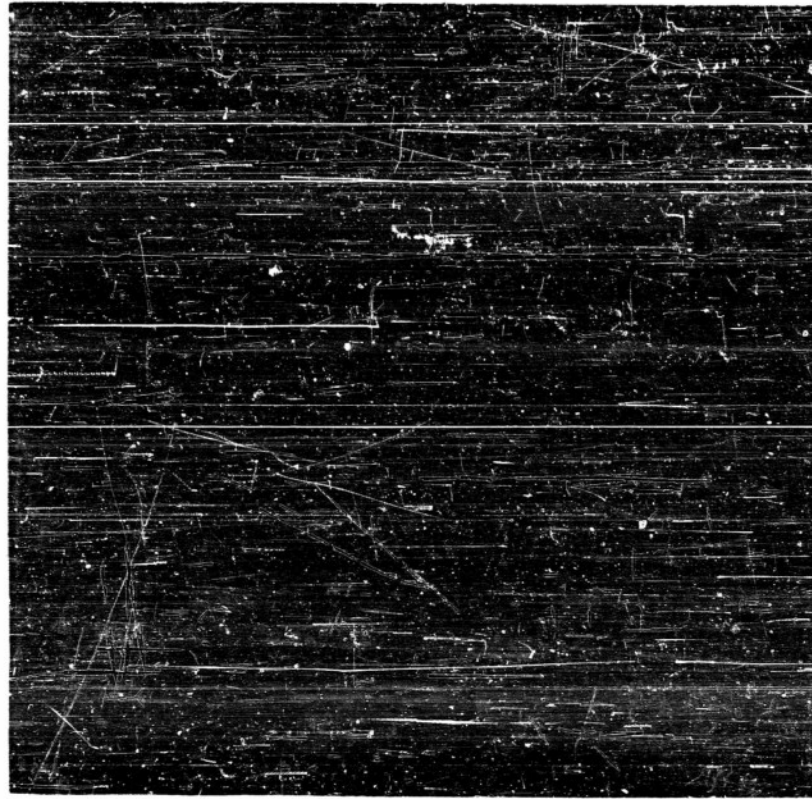
SLIGHT CRAZING WITHIN LAMINATE

FIG. 10 SLIGHT CRAZING WITHIN LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE



SLIGHT CRAZING WITHIN LAMINATE

FIG. 11 SLIGHT CRAZING WITHIN LAMINATE

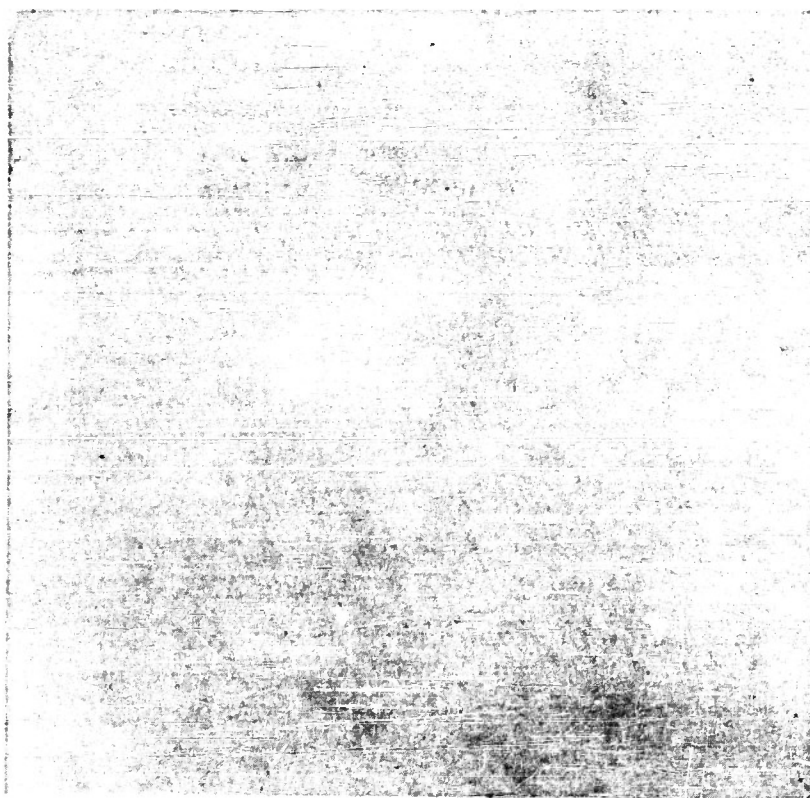
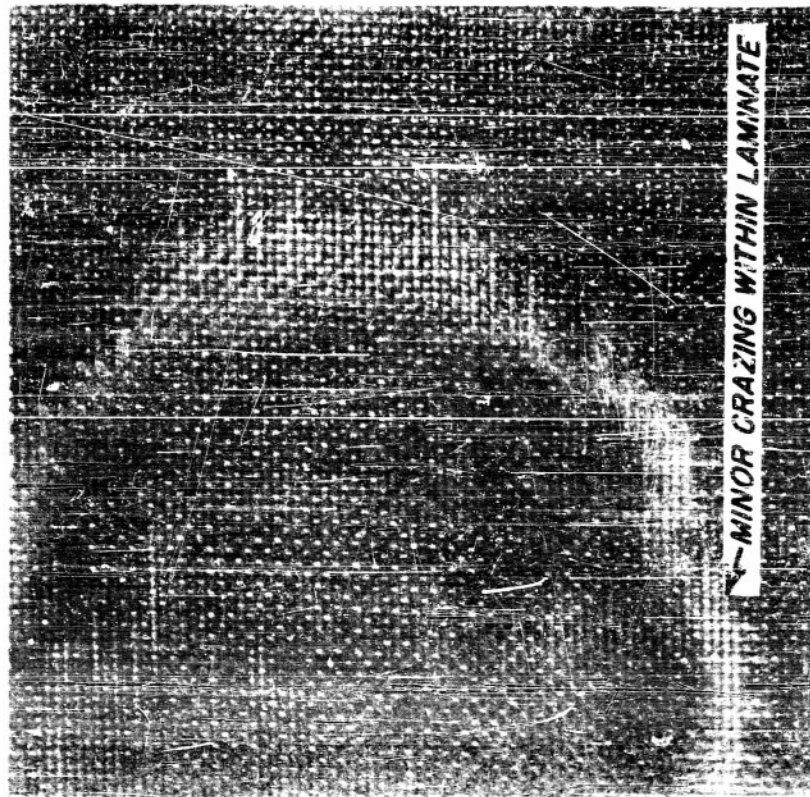
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG.12 MINOR CRAZING WITHIN LAMINATE

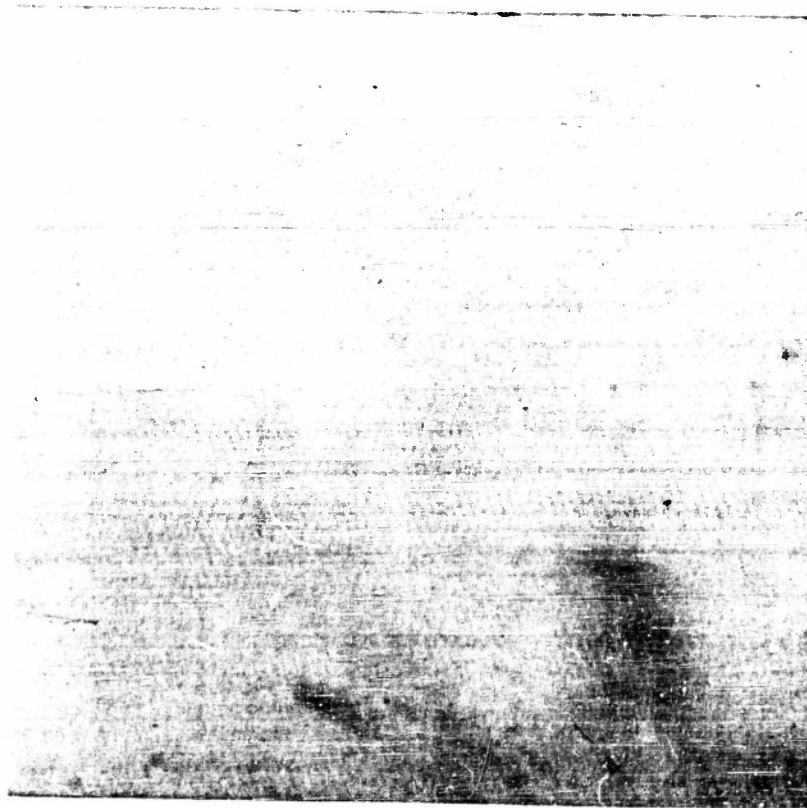
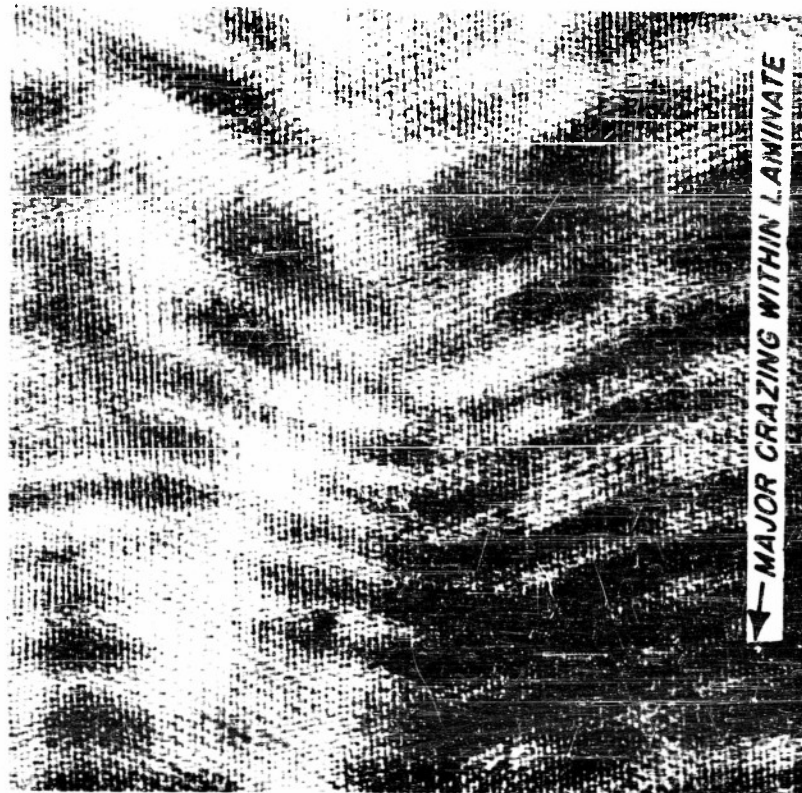
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 13 MINOR CRAZING WITHIN LAMINATE.

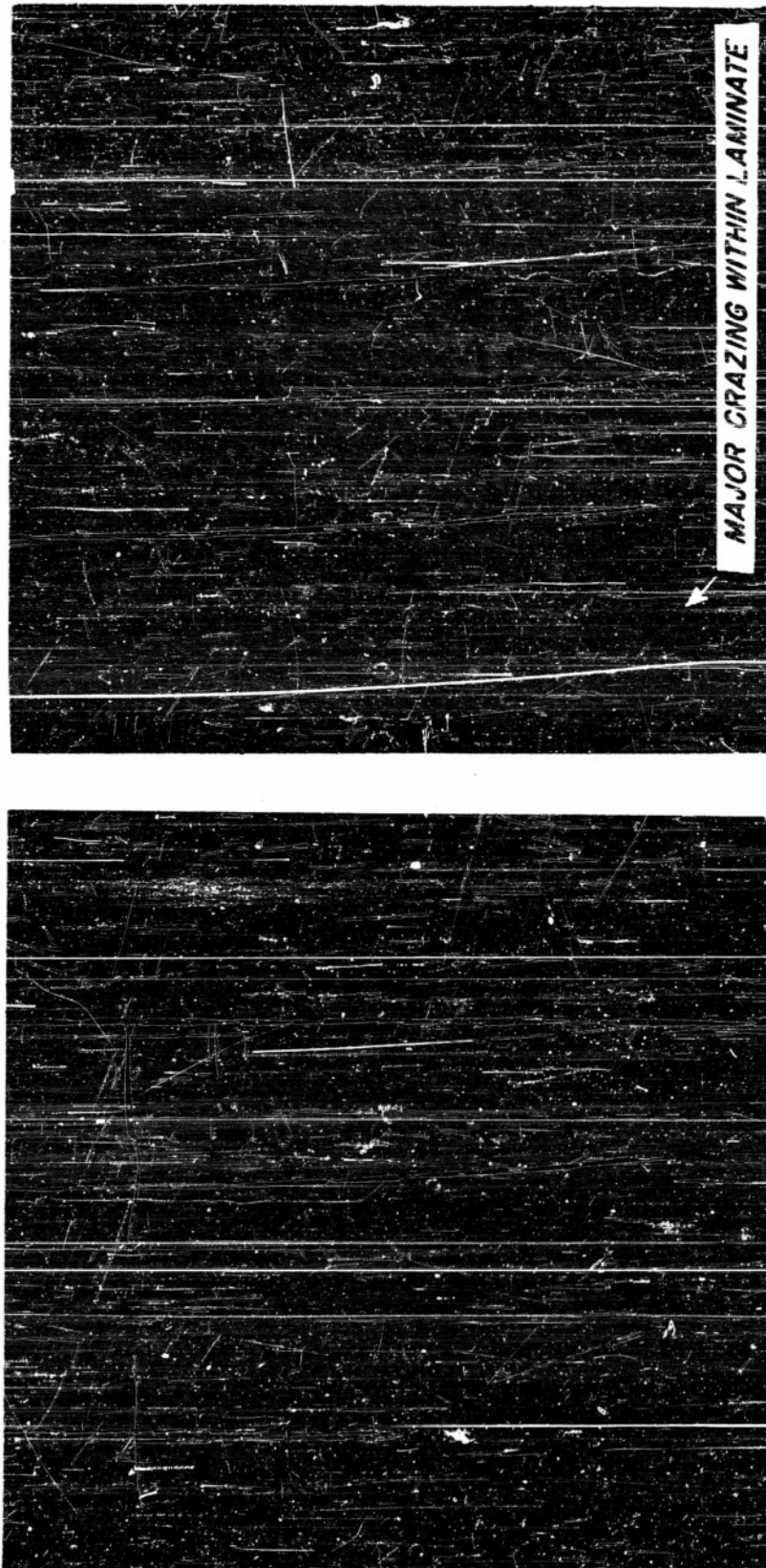
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG.14 MAJOR CRAZING WITHIN LAMINATE

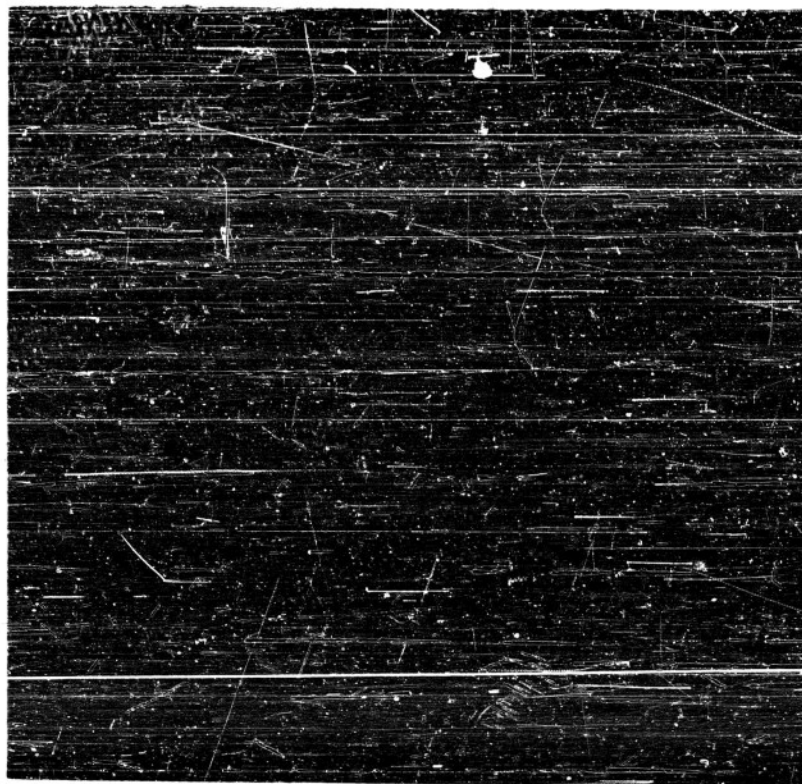
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 15 MAJOR CRAZING WITHIN LAMINATE

PHOTO BY TRANSMITTED LIGHT

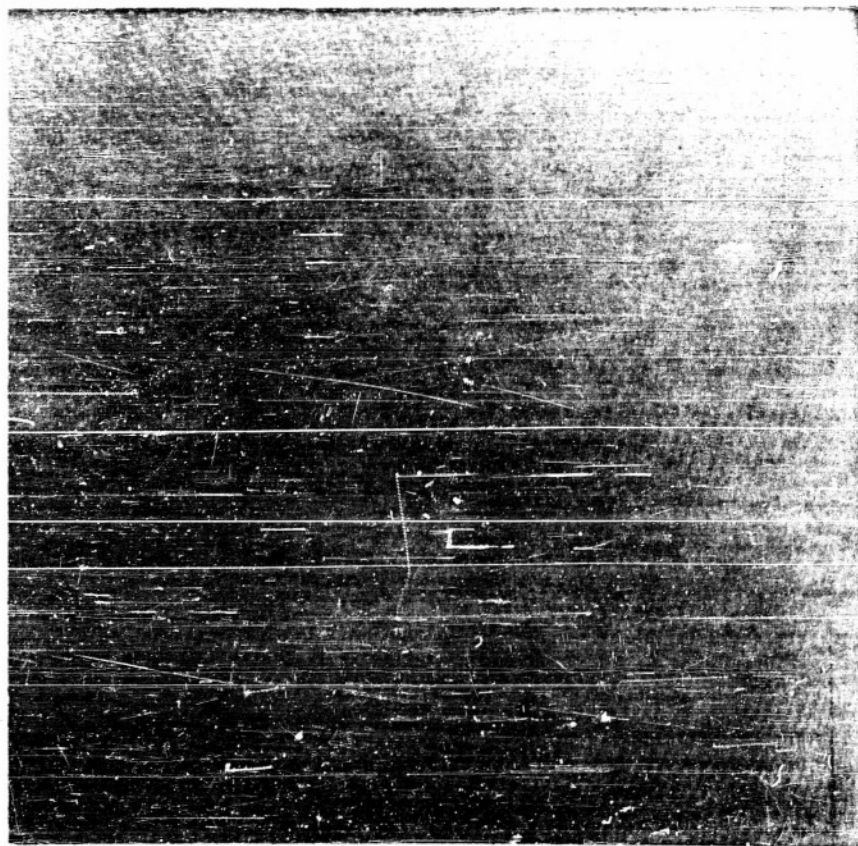


OPTIMUM QUALITY LAMINATE

"WHITE" LAMINATE

FIG. 16 "WHITE" LAMINATE

PHOTO BY REFLECTED LIGHT



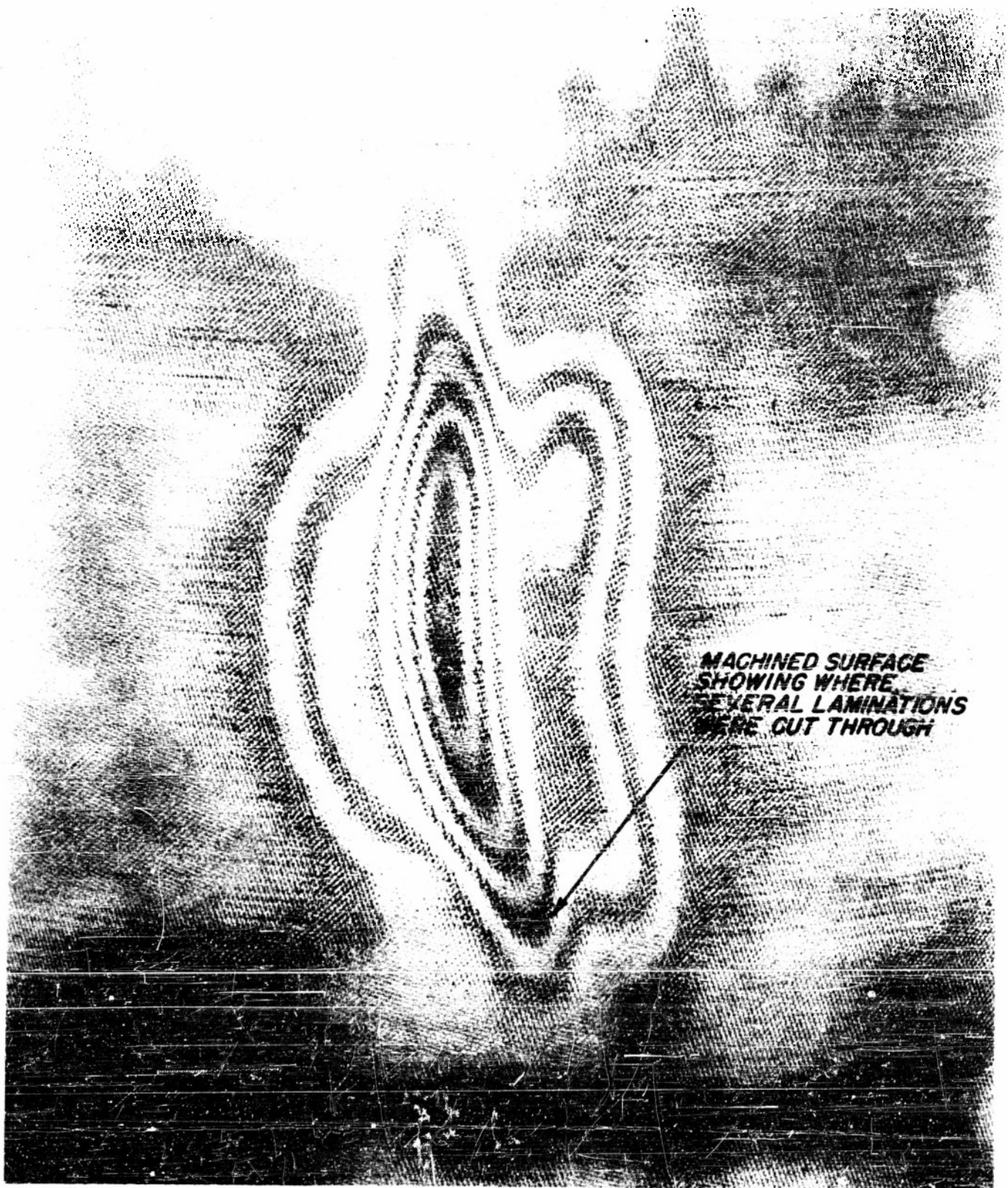
OPTIMUM QUALITY LAMINATE



"WHITE" LAMINATE

FIG. 17 "WHITE" LAMINATE

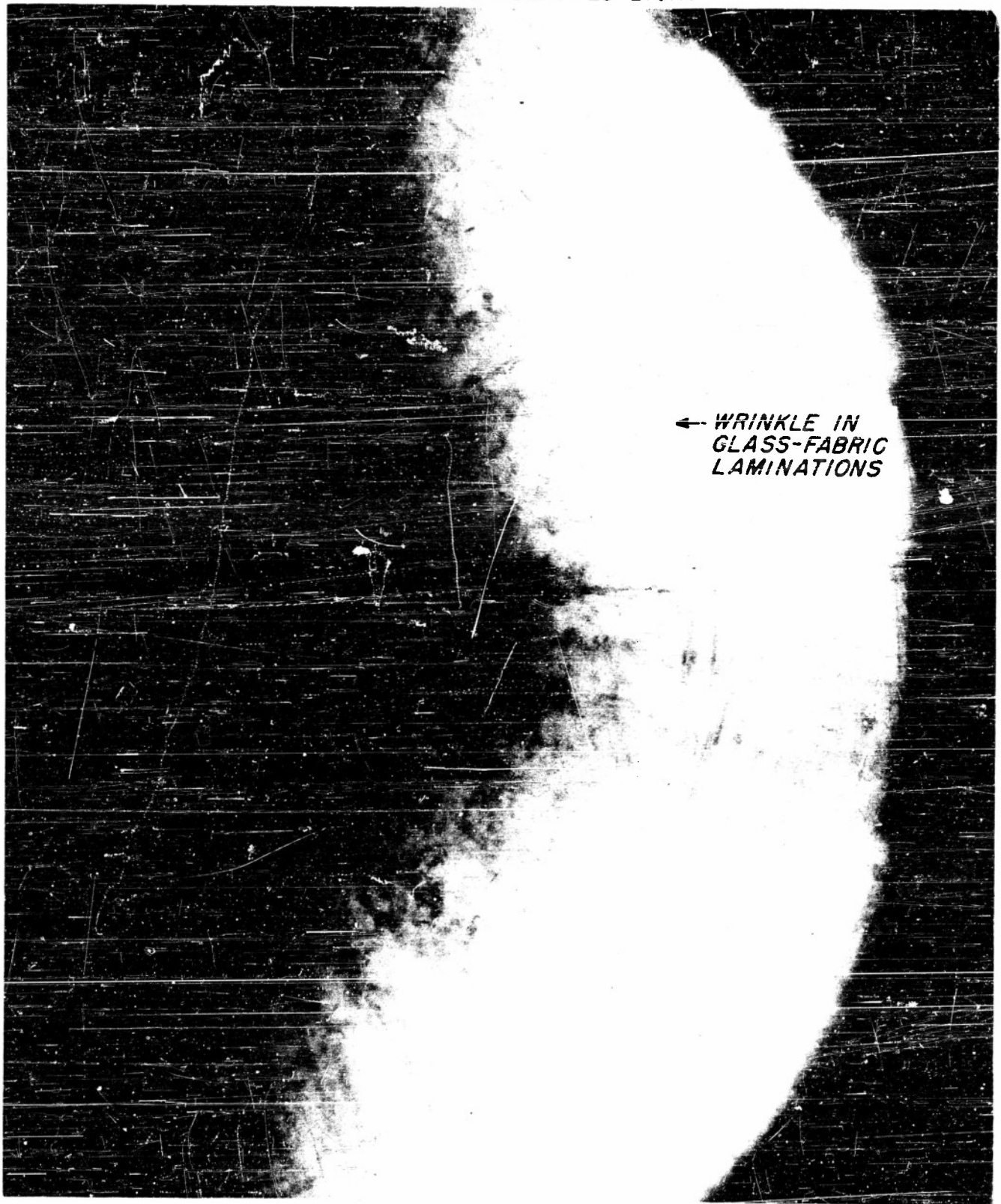
PHOTO BY REFLECTED LIGHT



**MACHINED SURFACE
SHOWING WHERE
SEVERAL LAMINATIONS
WERE CUT THROUGH**

FIG.19 MACHINED SURFACE OF LAMINATE

PHOTO BY TRANSMITTED LIGHT



← WRINKLE IN
GLASS-FABRIC
LAMINATIONS

FIG. 20 REINFORCEMENT WRINKLE

PHOTO BY REFLECTED LIGHT



FIG. 21 REINFORCEMENT WRINKLE AND RESIN POOL

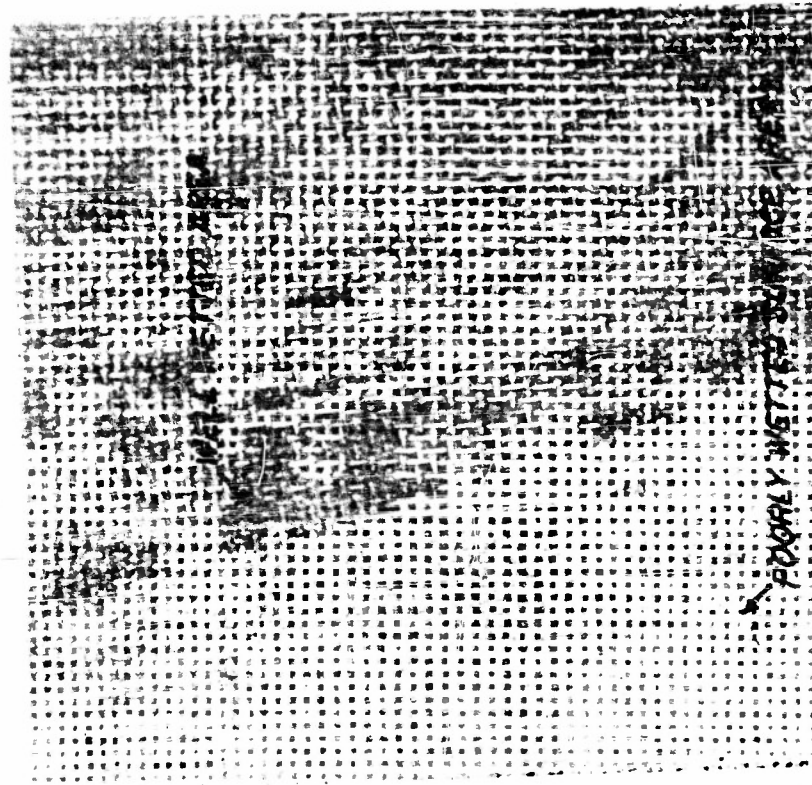
PHOTO BY TRANSMITTED LIGHT



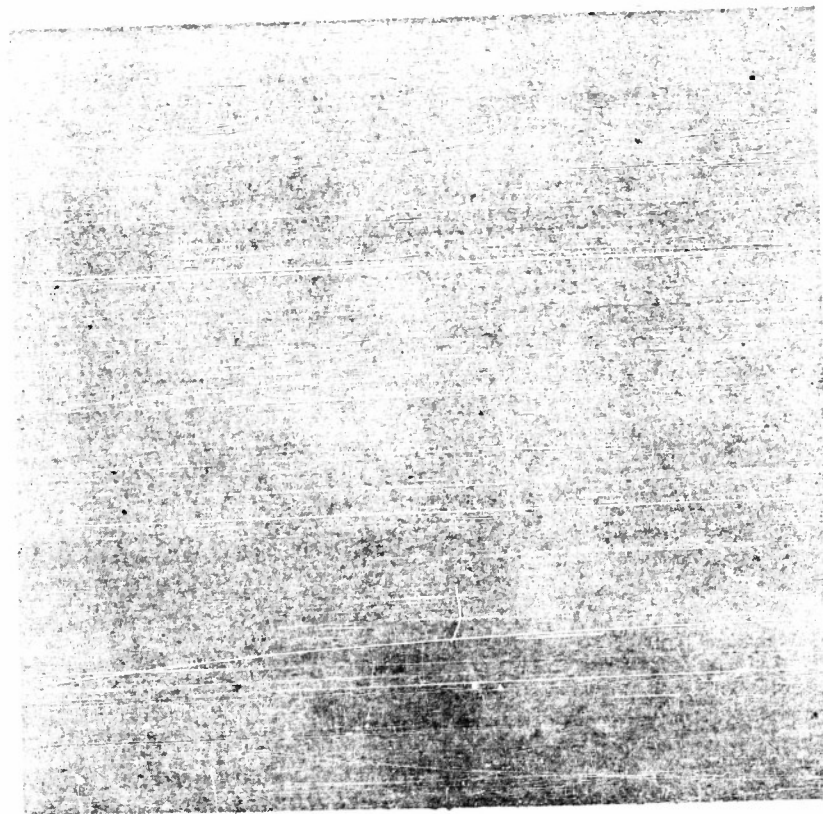
OPTIMUM QUALITY LAMINATE

FIG. 22 POORLY WETTED LAMINATE

PHOTO BY REFLECTED LIGHT



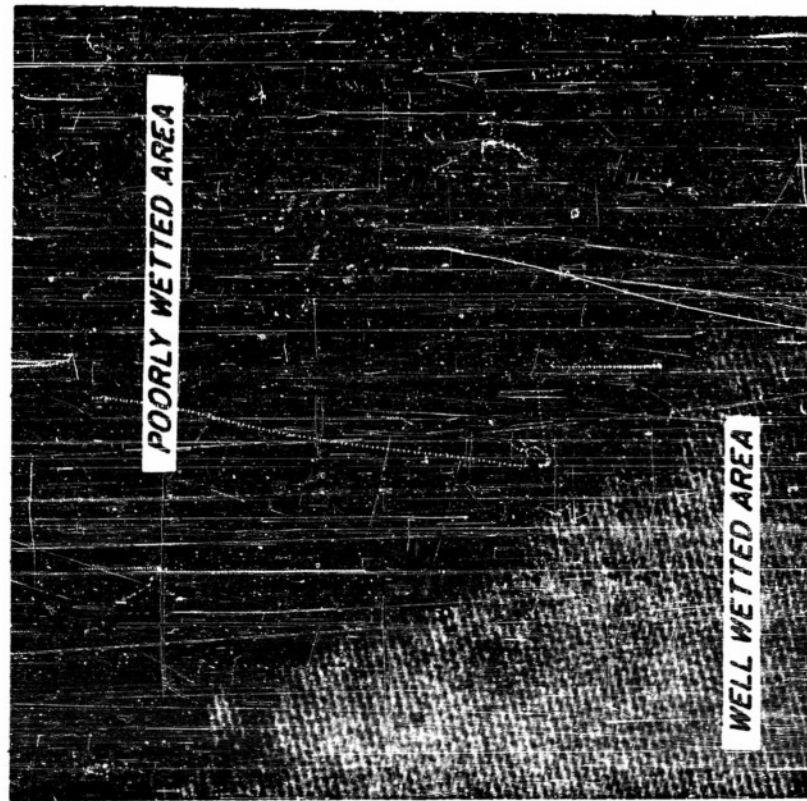
POORLY WETTED LAMINATE



OPTIMUM QUALITY LAMINATE

FIG. 23 POORLY WETTED LAMINATE

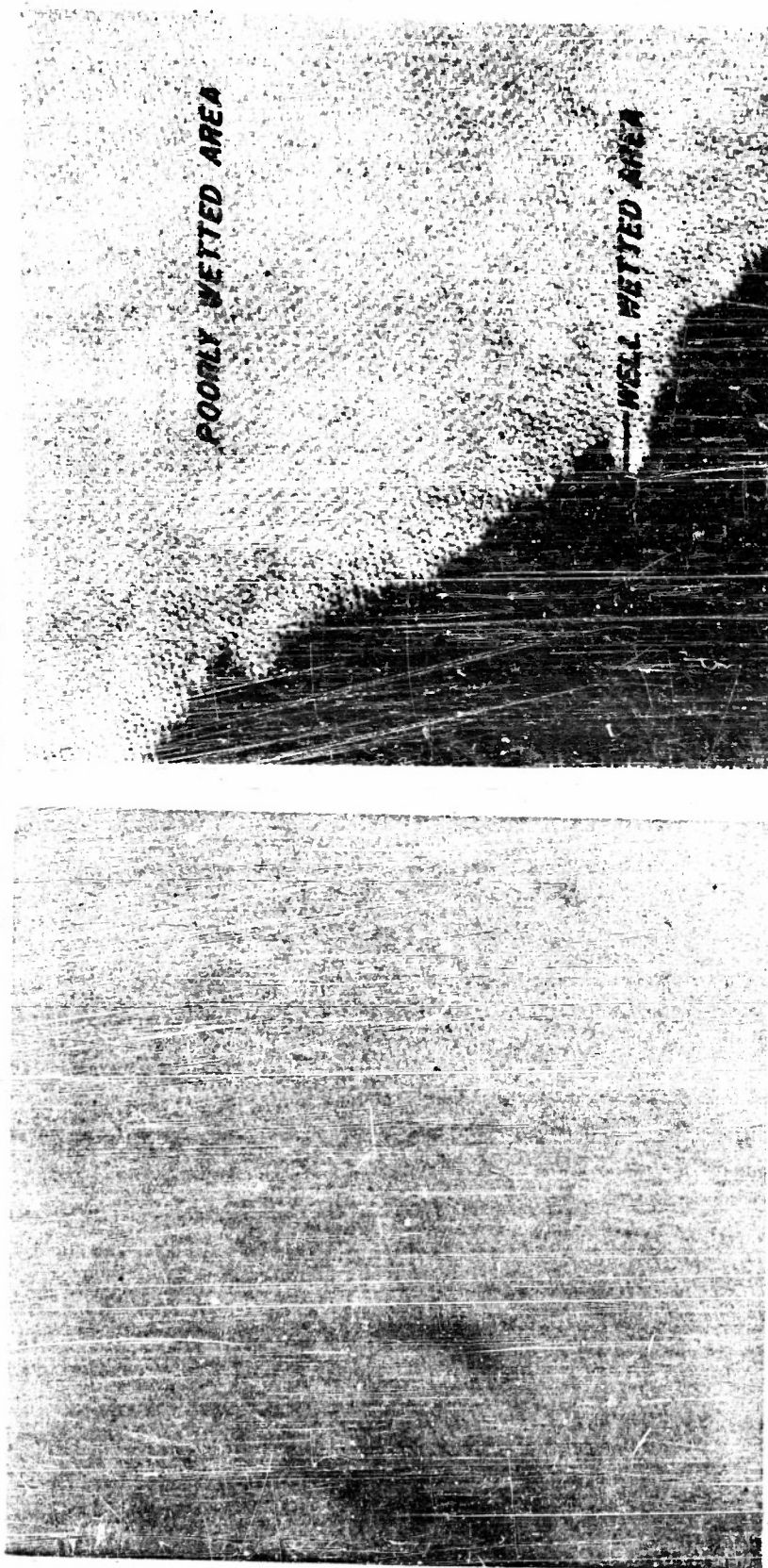
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 24 POORLY WETTED LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 25 POORLY WETTED LAMINATE

PHOTO BY TRANSMITTED LIGHT

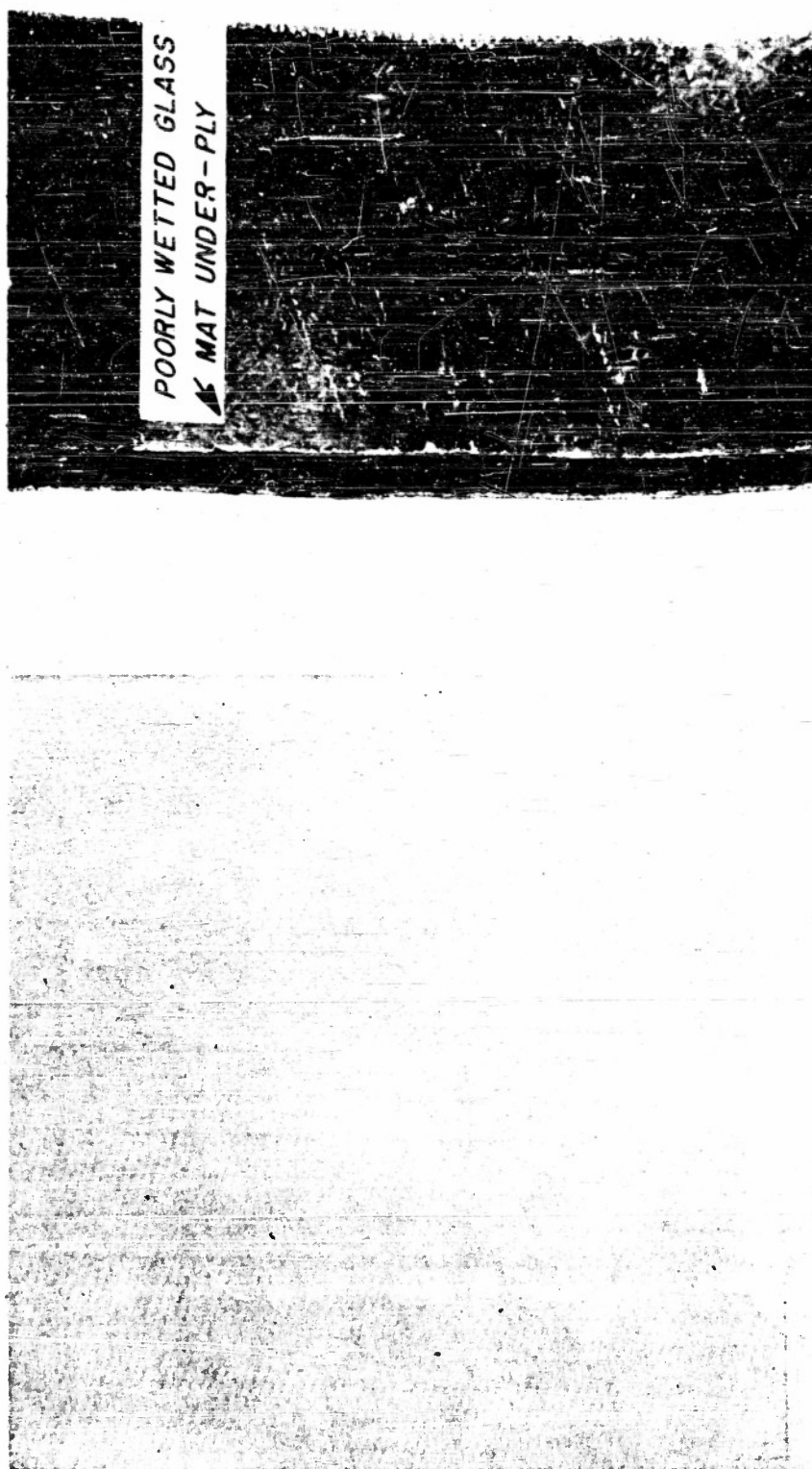


POORLY WETTED
GLASS MAT
UNDER - PLY

OPTIMUM QUALITY LAMINATE

FIG. 26 POORLY WETTED UNDER-PLIES IN LAMINATE

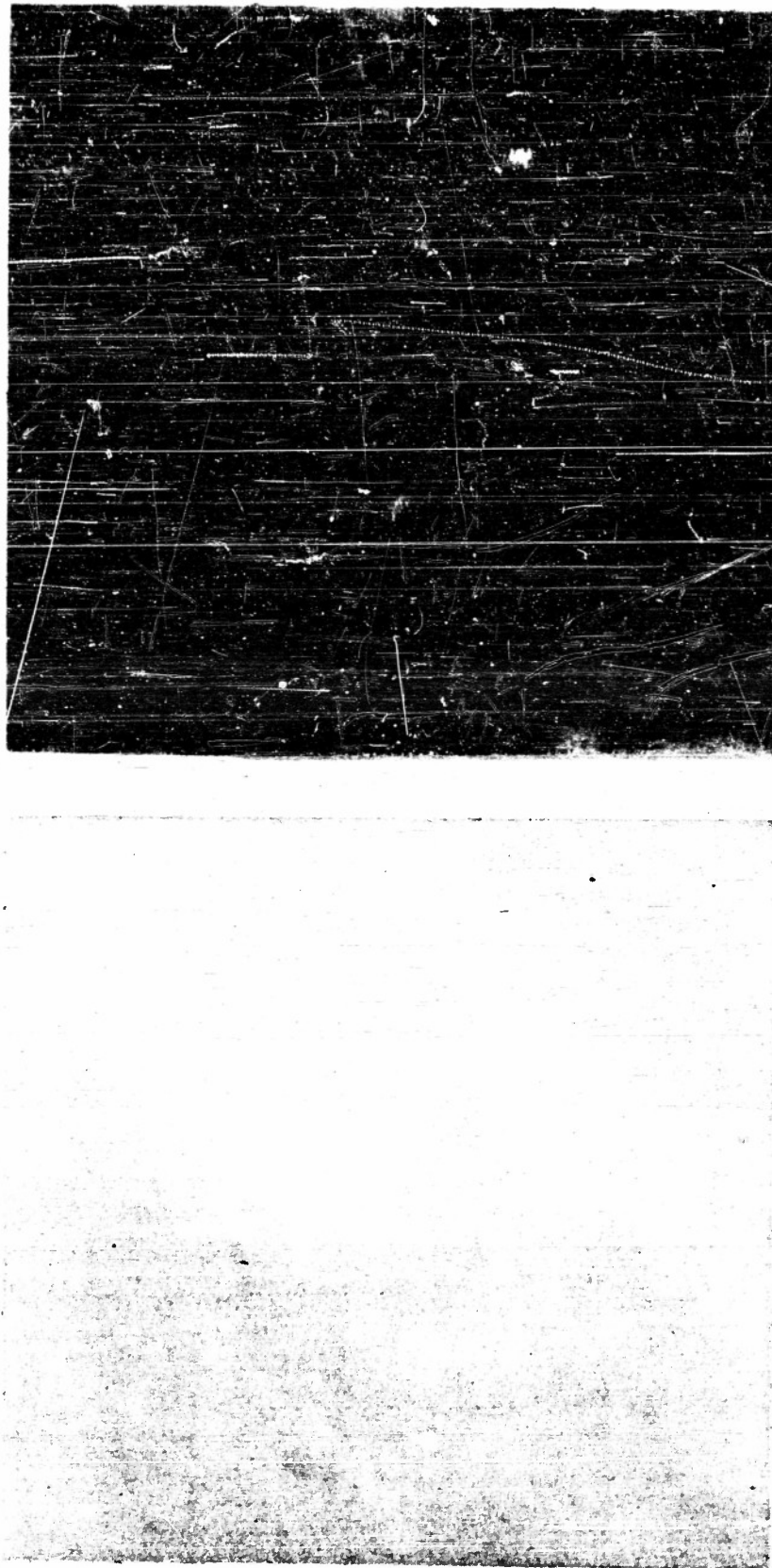
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 27 POORLY WETTED UNDER-PLIES IN LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

POORLY WETTED GLASS MAT UNDER-PLY

FIG. 28 POORLY WETTED UNDER-PLIES IN LAMINATE

PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 29 INTERPLY DELAMINATION

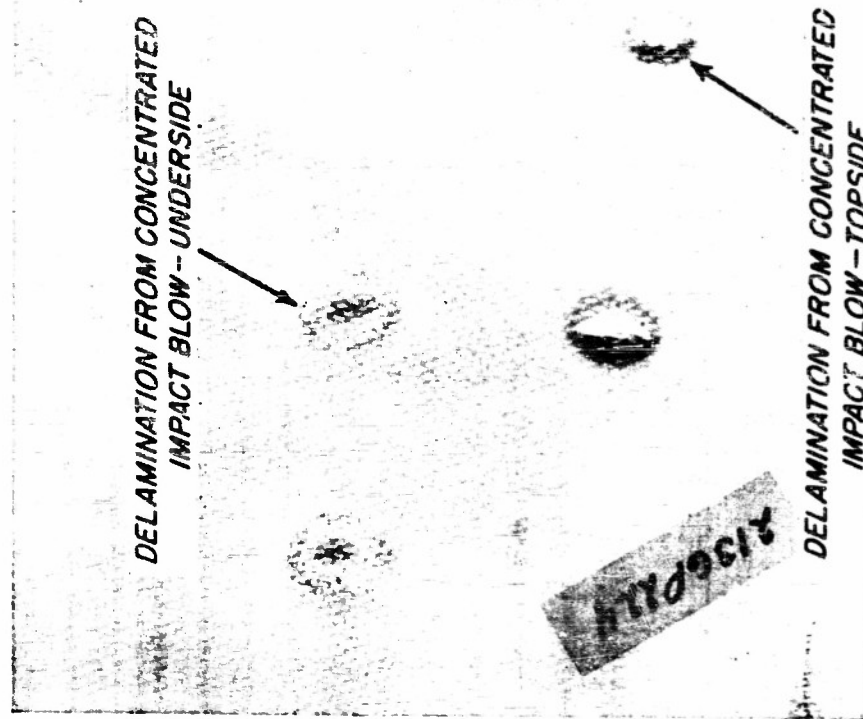
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 30 INTERPLY DELAMINATION

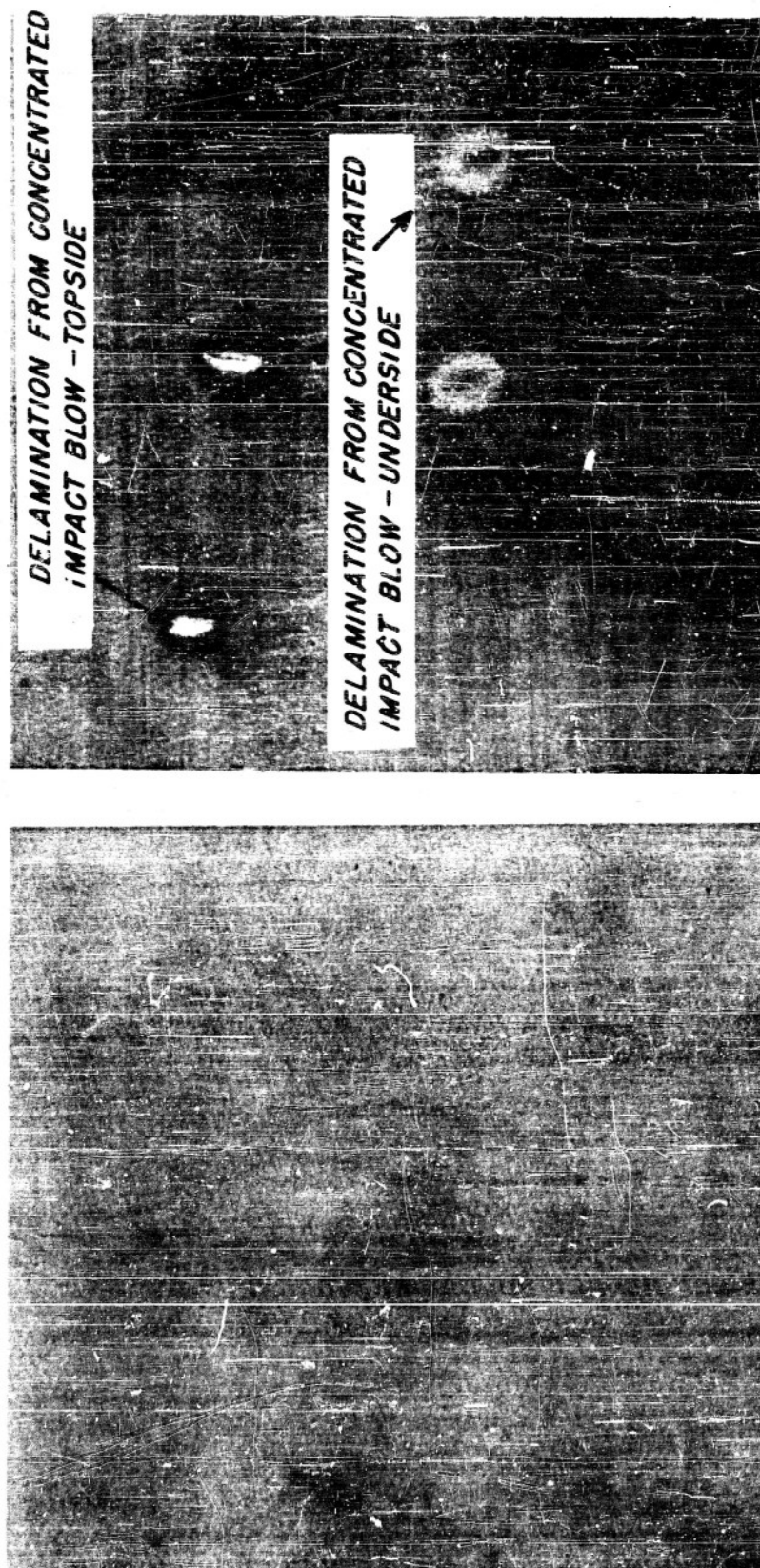
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG.31 IMPACT DELAMINATIONS

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

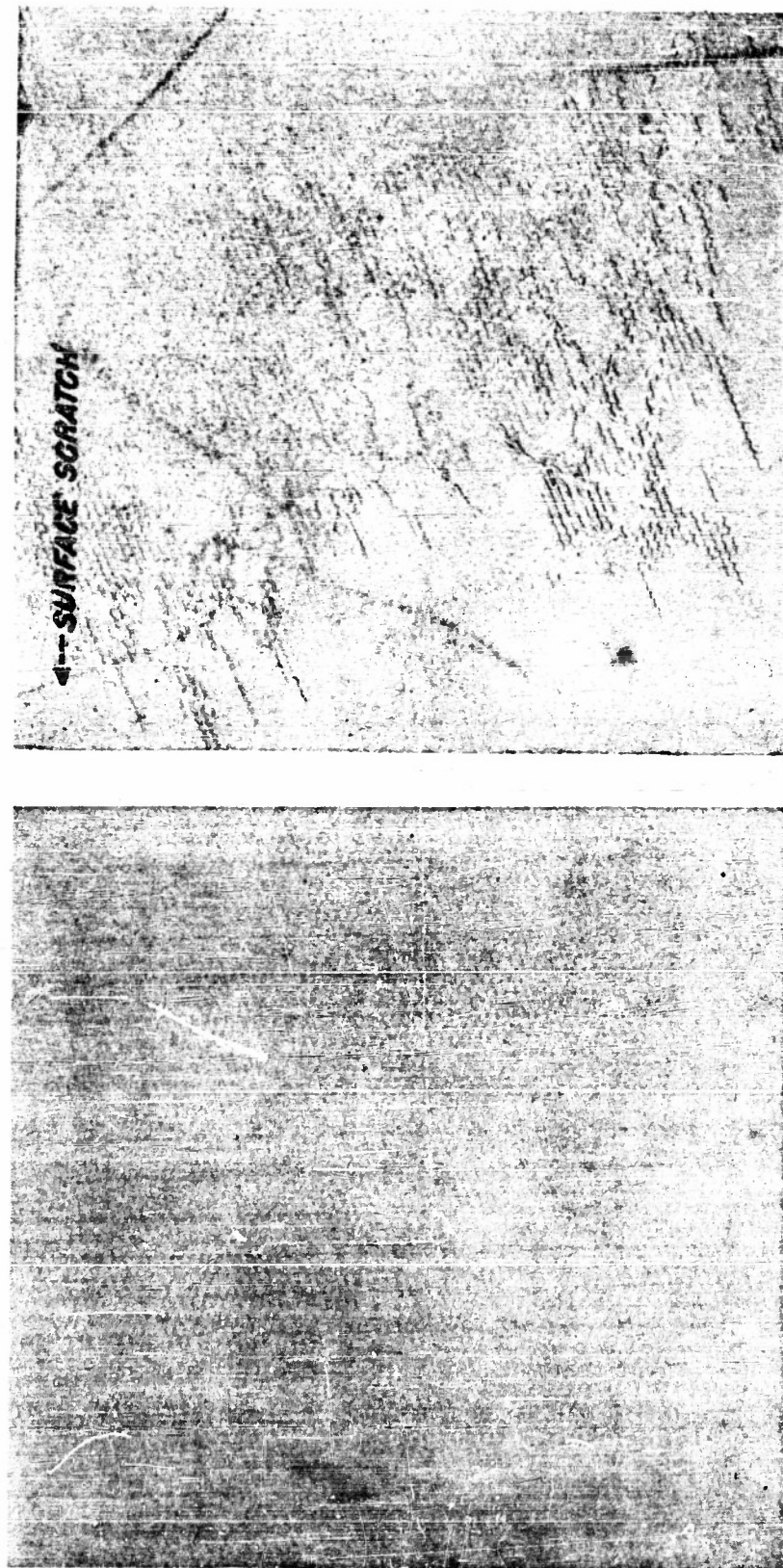
FIG.32 IMPACT DELAMINATIONS

PHOTO BY REFLECTED LIGHT



FIG. 33 PATCHES

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

SURFACE UNEVENNESS

FIG.34 SURFACE UNEVENNESS

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PHOTO BY REFLECTED LIGHT



SURFACE PITS

FIG. 35 SURFACE PITS

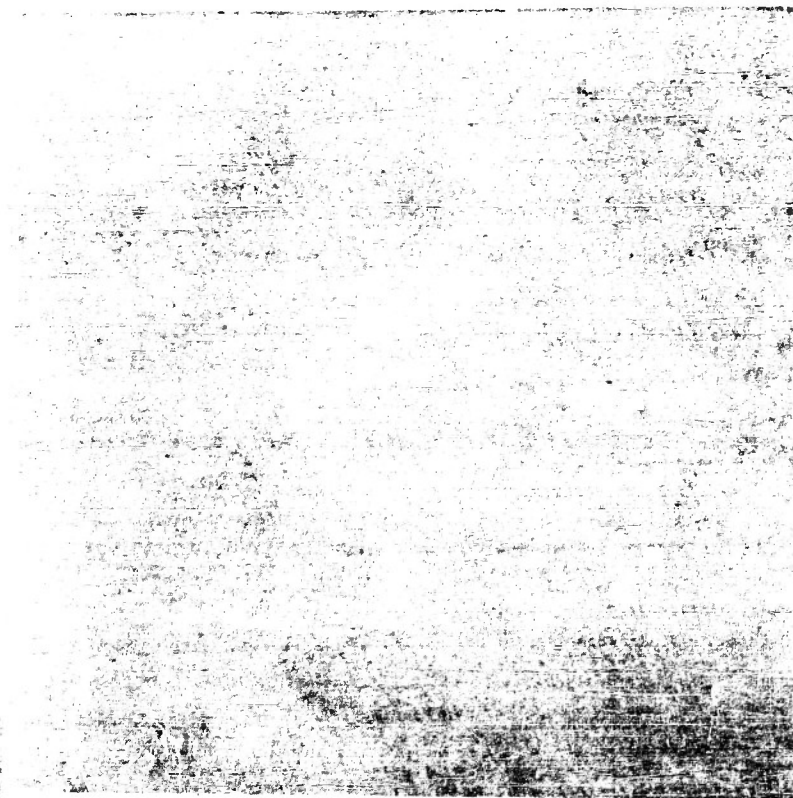
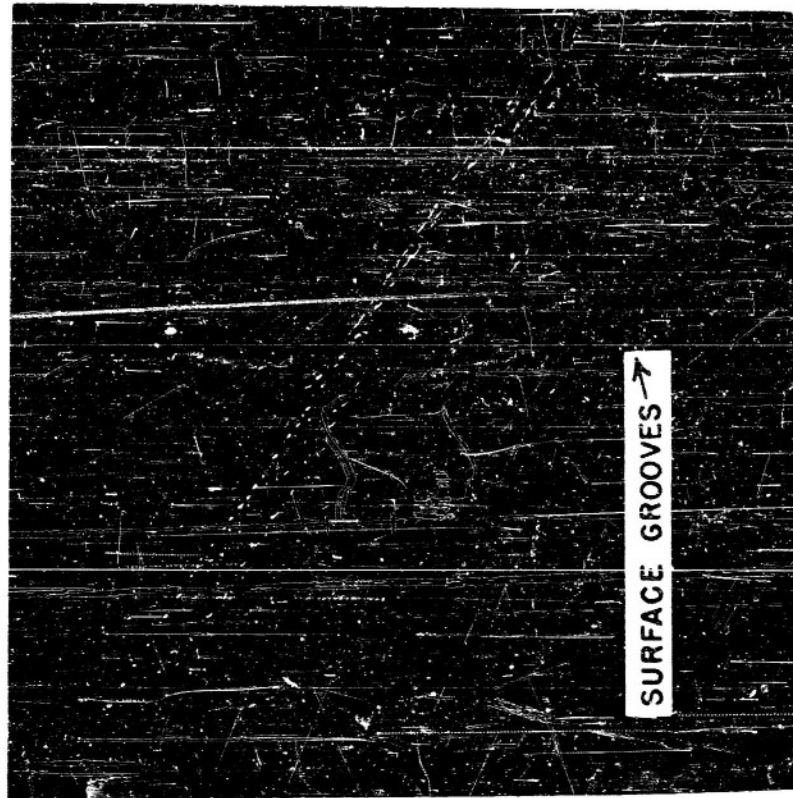
PHOTO BY REFLECTED LIGHT

SEVERE SURFACE PIT



FIG. 36 SURFACE PITS

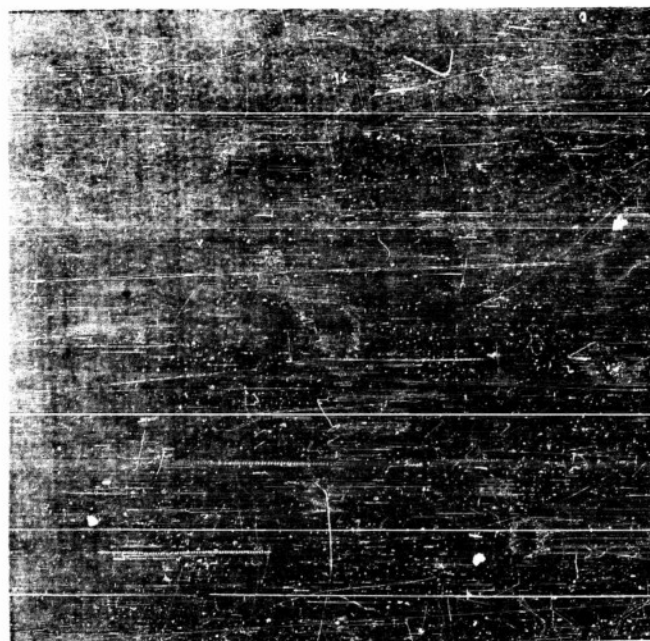
PHOTO BY REFLECTED LIGHT



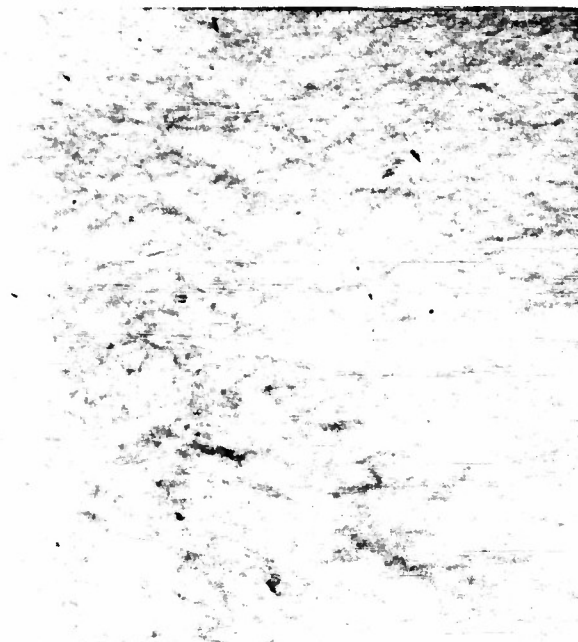
OPTIMUM QUALITY LAMINATE

FIG. 37 SURFACE GROOVES

PHOTO BY REFLECTED LIGHT



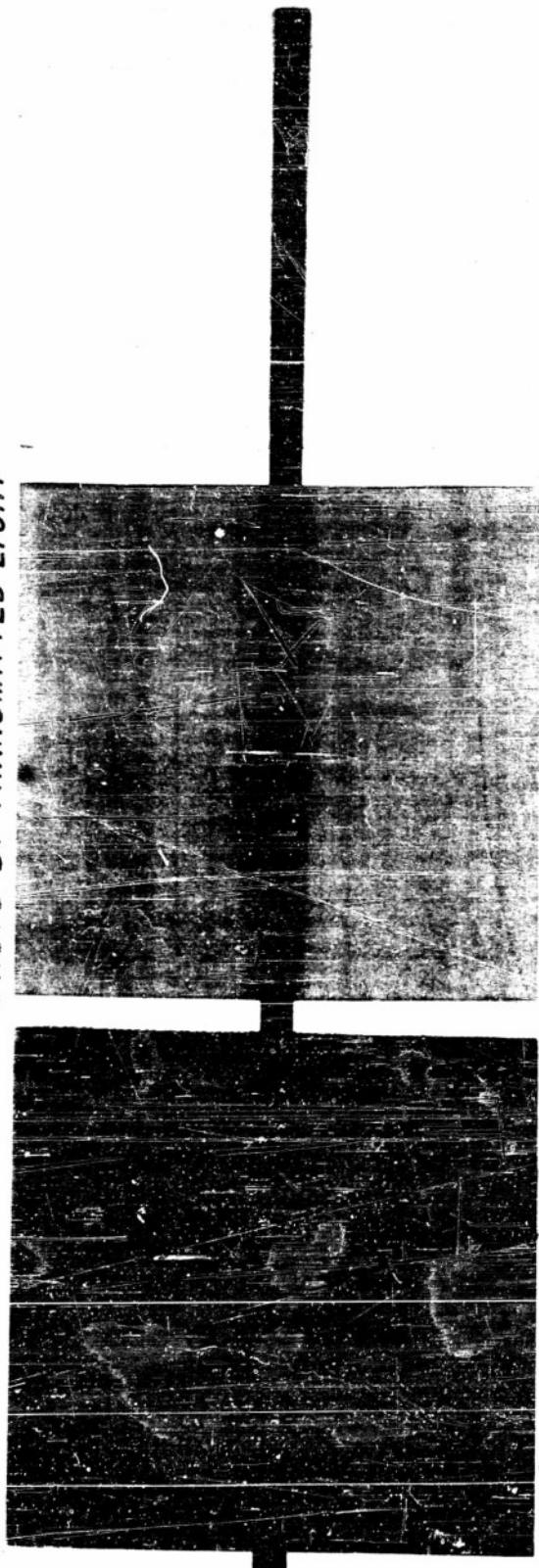
GLASS CLOTH LAMINATE



GLASS MAT LAMINATE

FIG. 1 OPTIMUM QUALITY LAMINATES

PHOTO BY TRANSMITTED LIGHT



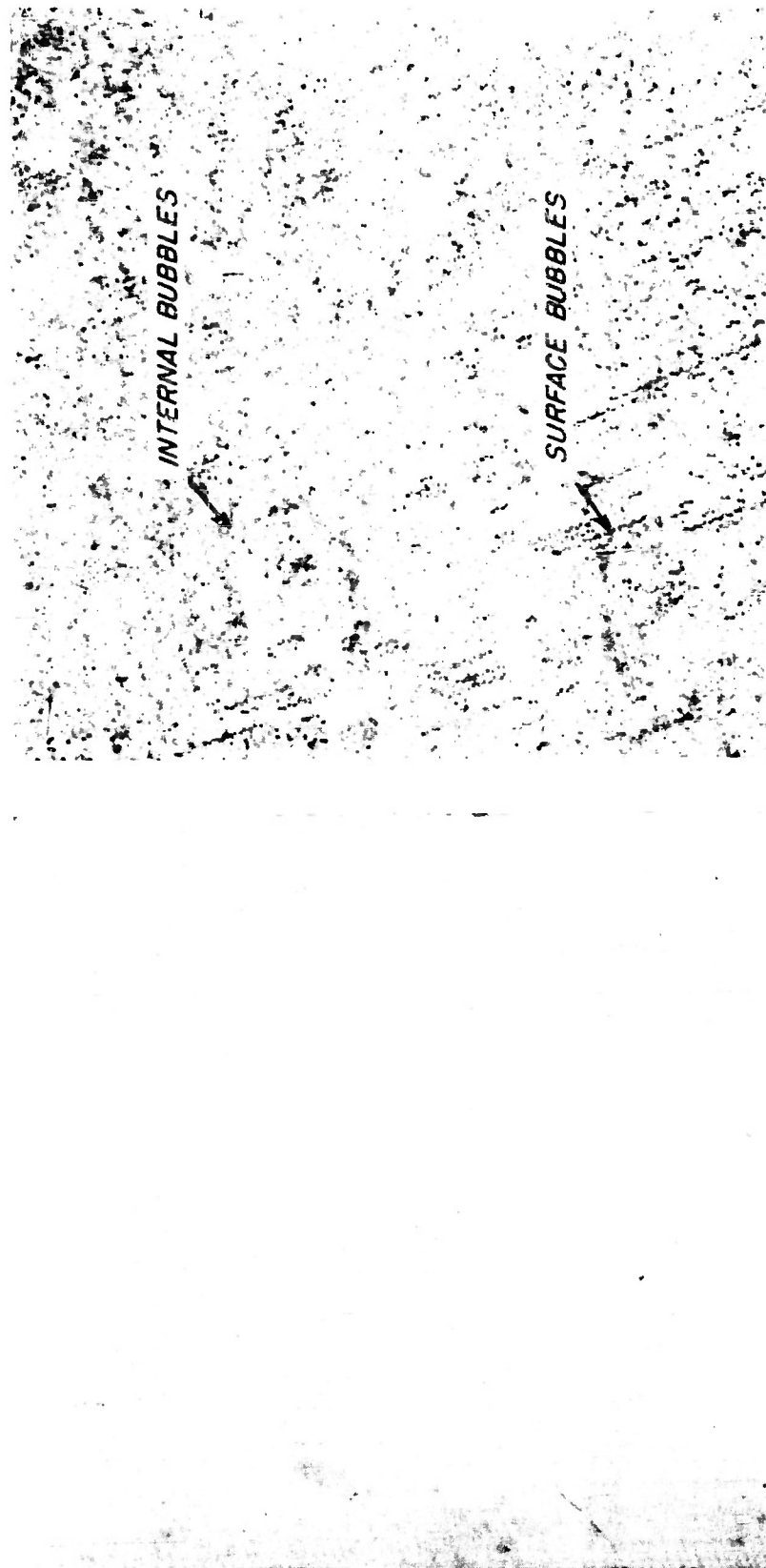
0".475 THICK LAMINATE 0".175 THICK LAMINATE 0".150 THICK LAMINATE
FIG. 2 TRANSLUCENCY VARIATION OF LAMINATES WITH THICKNESS

PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE MINOR AMOUNTS OF AIR AND GAS BUBBLES
FIG. 3 MINOR AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY TRANSMITTED LIGHT

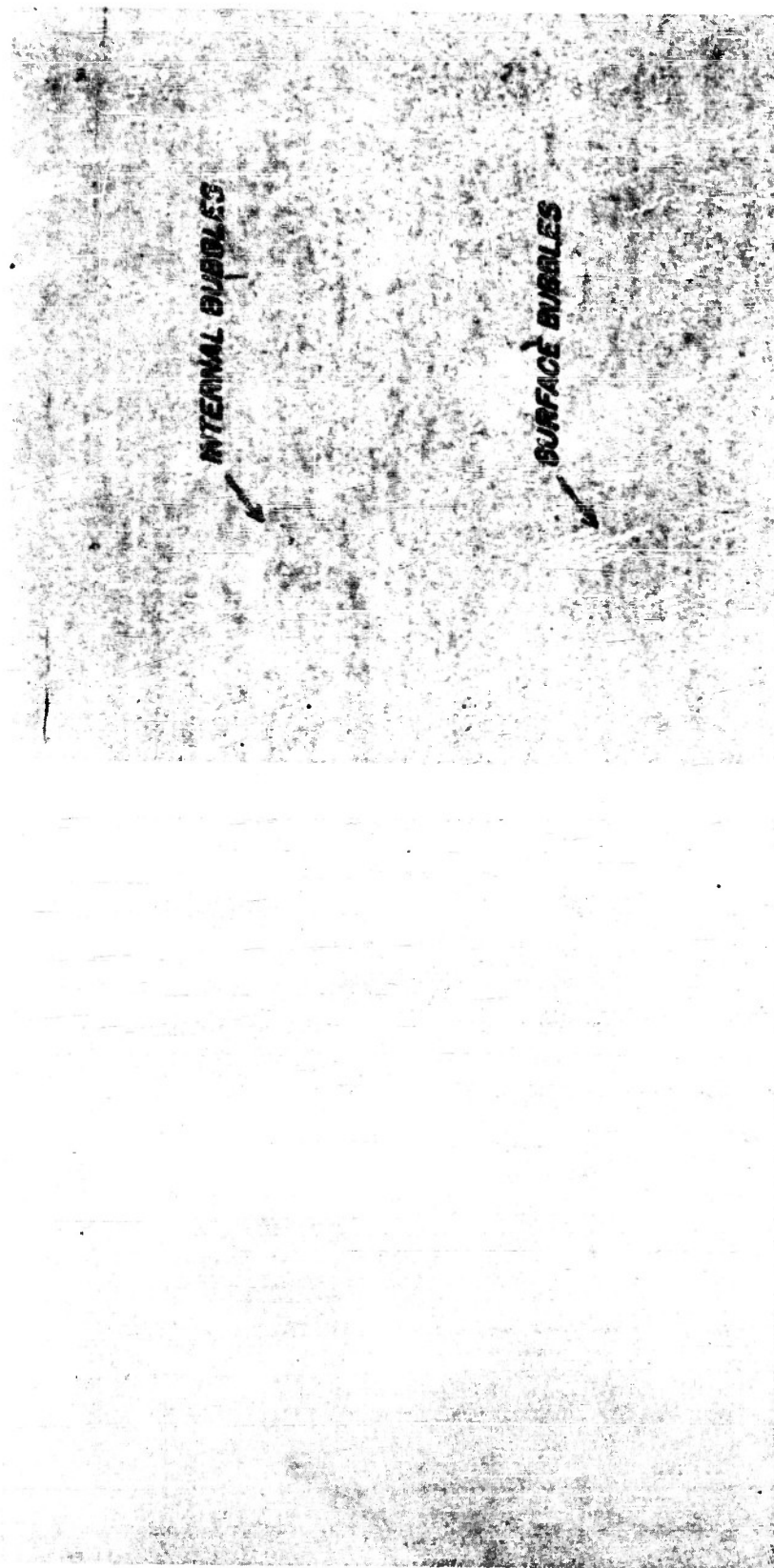


OPTIMUM QUALITY LAMINATE

MAJOR AMOUNT OF AIR AND GAS BUBBLES

FIG. 5 MAJOR AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY REFLECTED LIGHT

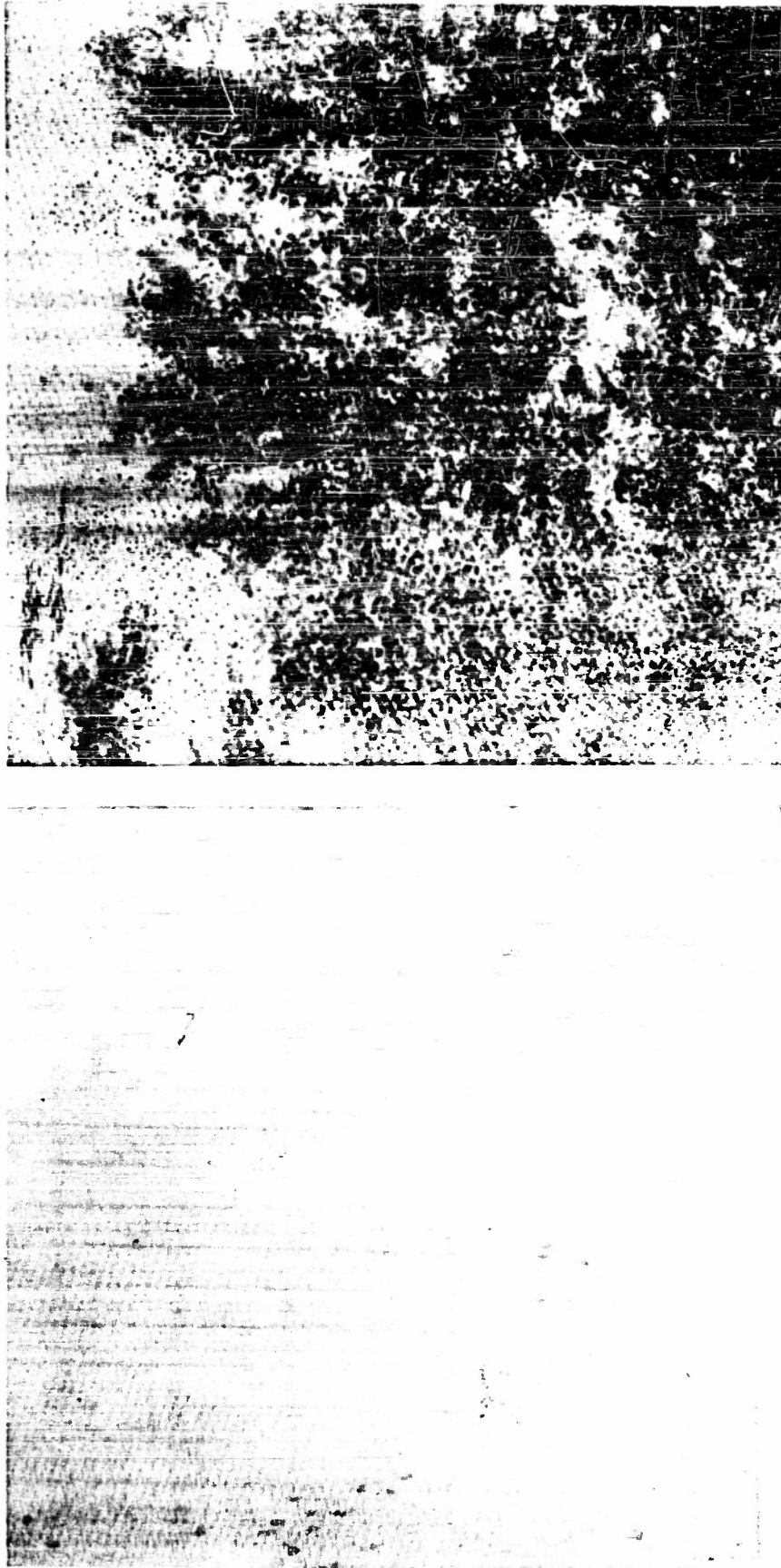


OPTIMUM QUALITY LAMINATE

MAJOR AMOUNT OF AIR AND GAS BUBBLES

FIG. 6 MAJOR AMOUNTS OF AIR AND GAS BUBBLES

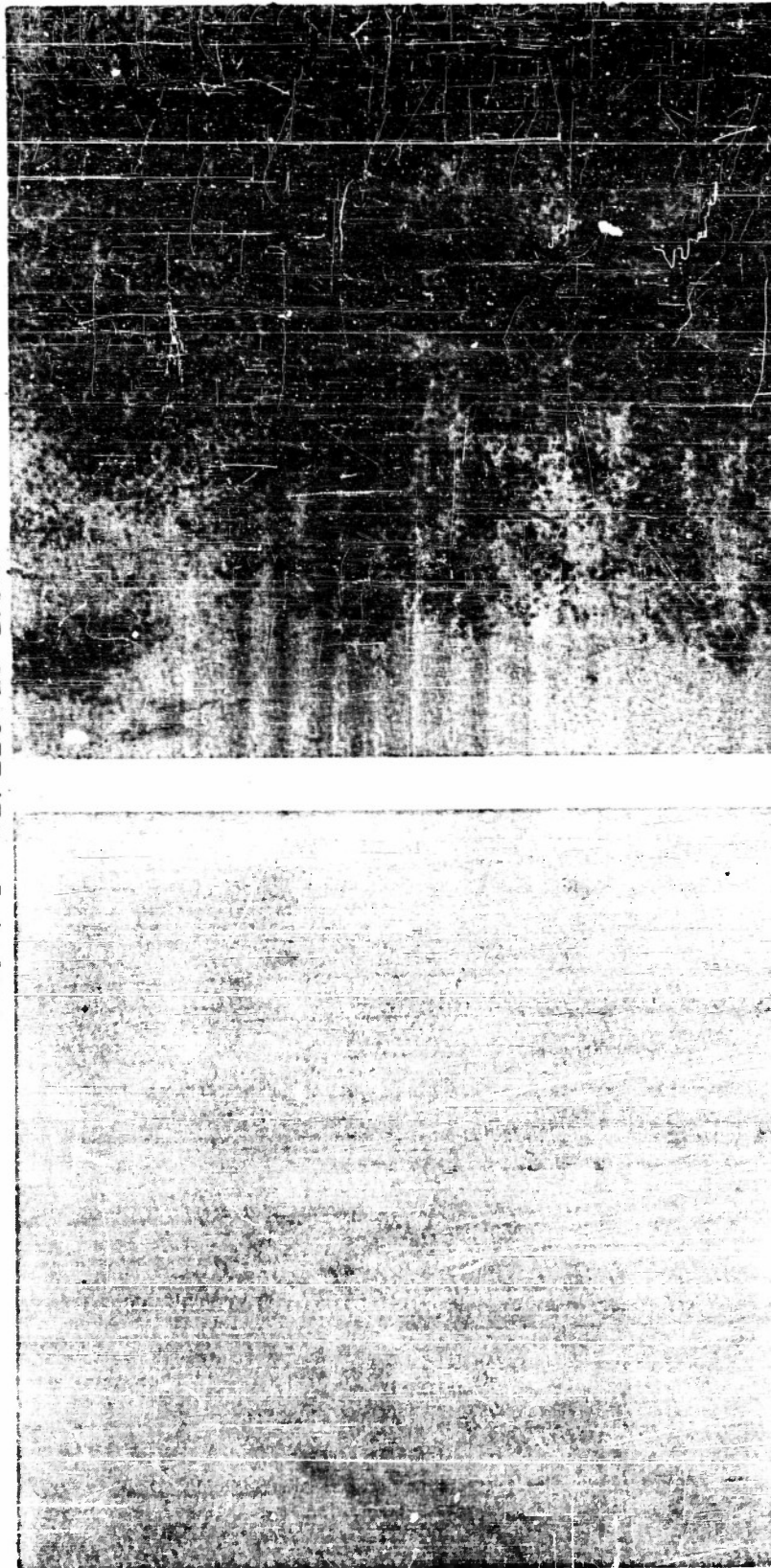
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

FIG. 7 EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

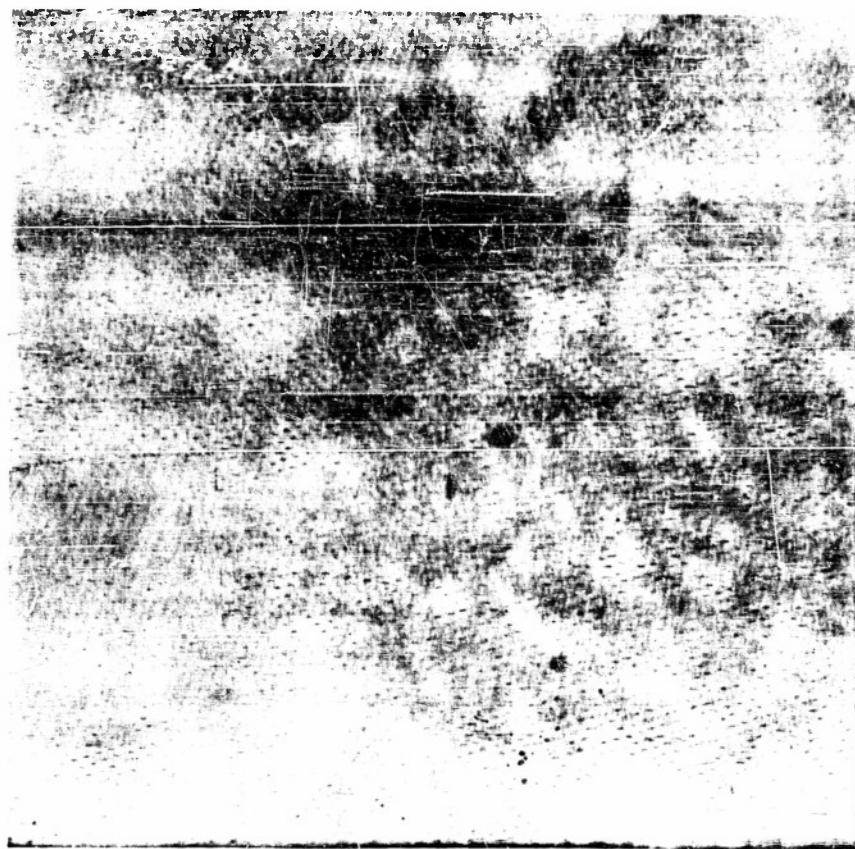
FIG. 8 EXCESSIVE AMOUNTS OF AIR AND GAS BUBBLES

PHOTO BY REFLECTED LIGHT



FIG.9 RESIN STARVED LAMINATES

PHOTO BY TRANSMITTED LIGHT

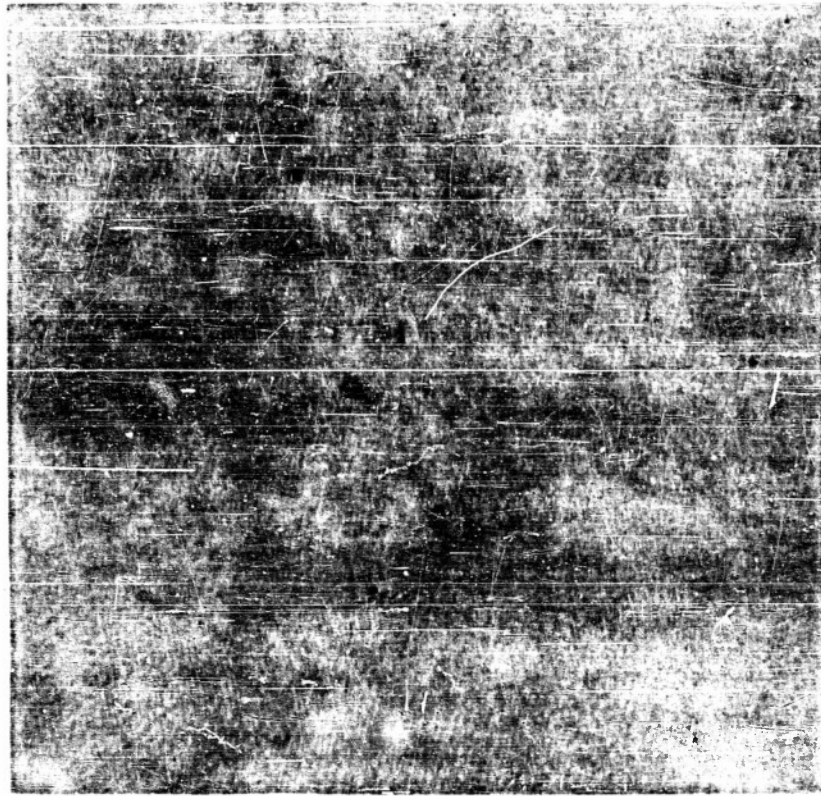


OPTIMUM QUALITY LAMINATE

SLIGHT CRAZING WITHIN LAMINATE

FIG.10 SLIGHT CRAZING WITHIN LAMINATE

PHOTO BY REFLECTED LIGHT



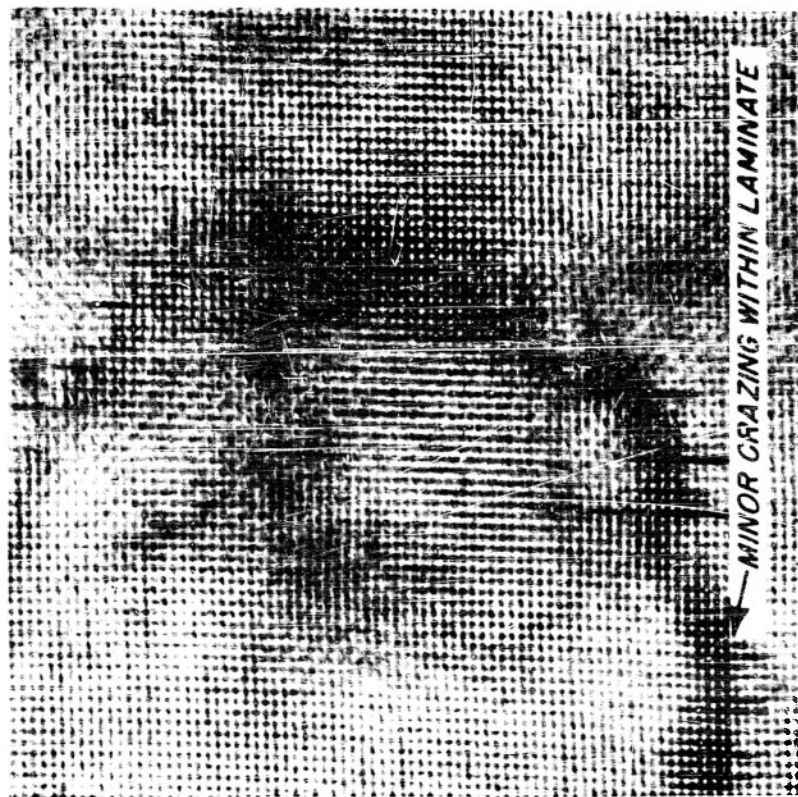
SLIGHT CRAZING WITHIN LAMINATE



OPTIMUM QUALITY LAMINATE

FIG. 11 SLIGHT CRAZING WITHIN LAMINATE

PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG.12 MINOR CRAZING WITHIN LAMINATE

PHOTO BY REFLECTED LIGHT

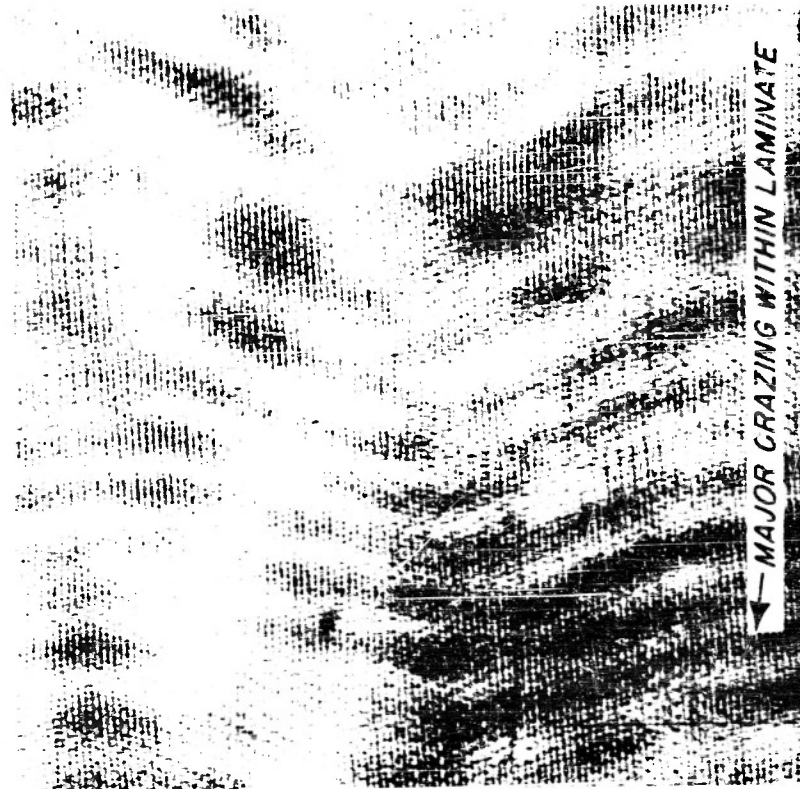


MINOR CRAZING WITHIN LAMINATE

OPTIMUM QUALITY LAMINATE

FIG. 13 MINOR CRAZING WITHIN LAMINATE

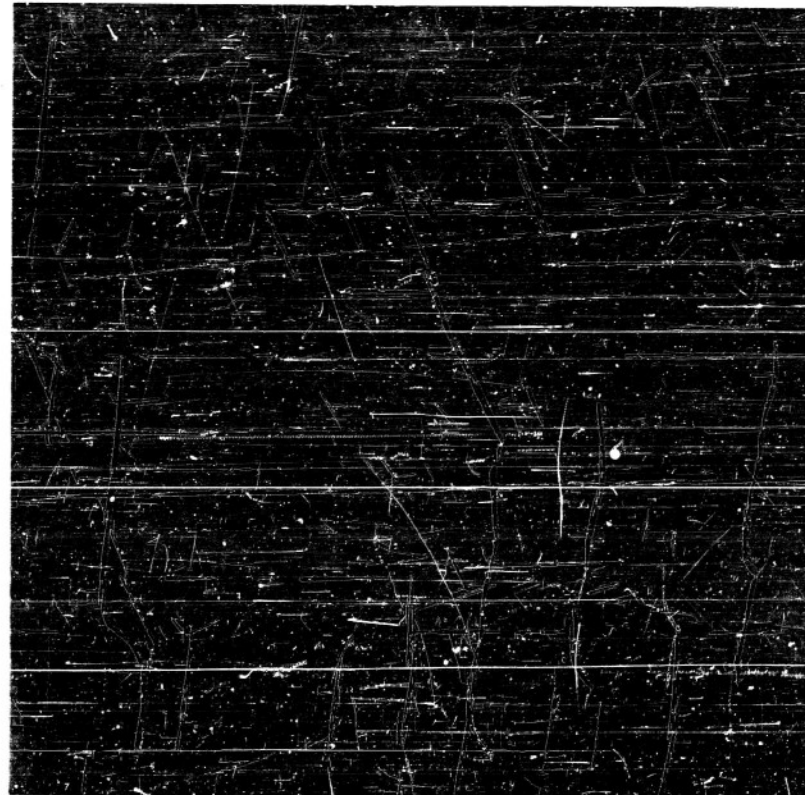
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 14 MAJOR CRAZING WITHIN LAMINATE

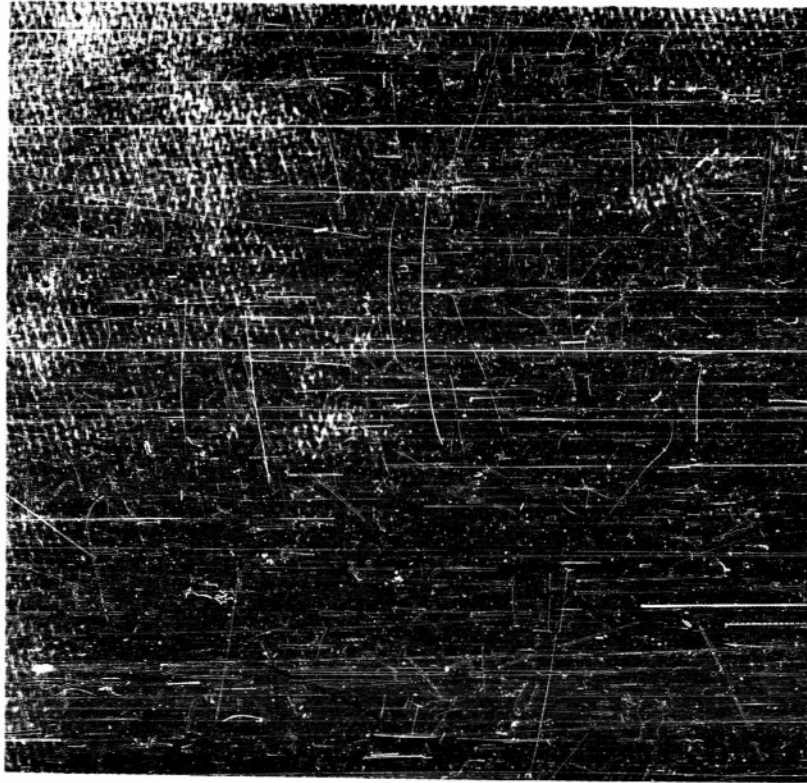
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 15 MAJOR CRAZING WITHIN LAMINATE

PHOTO BY TRANSMITTED LIGHT

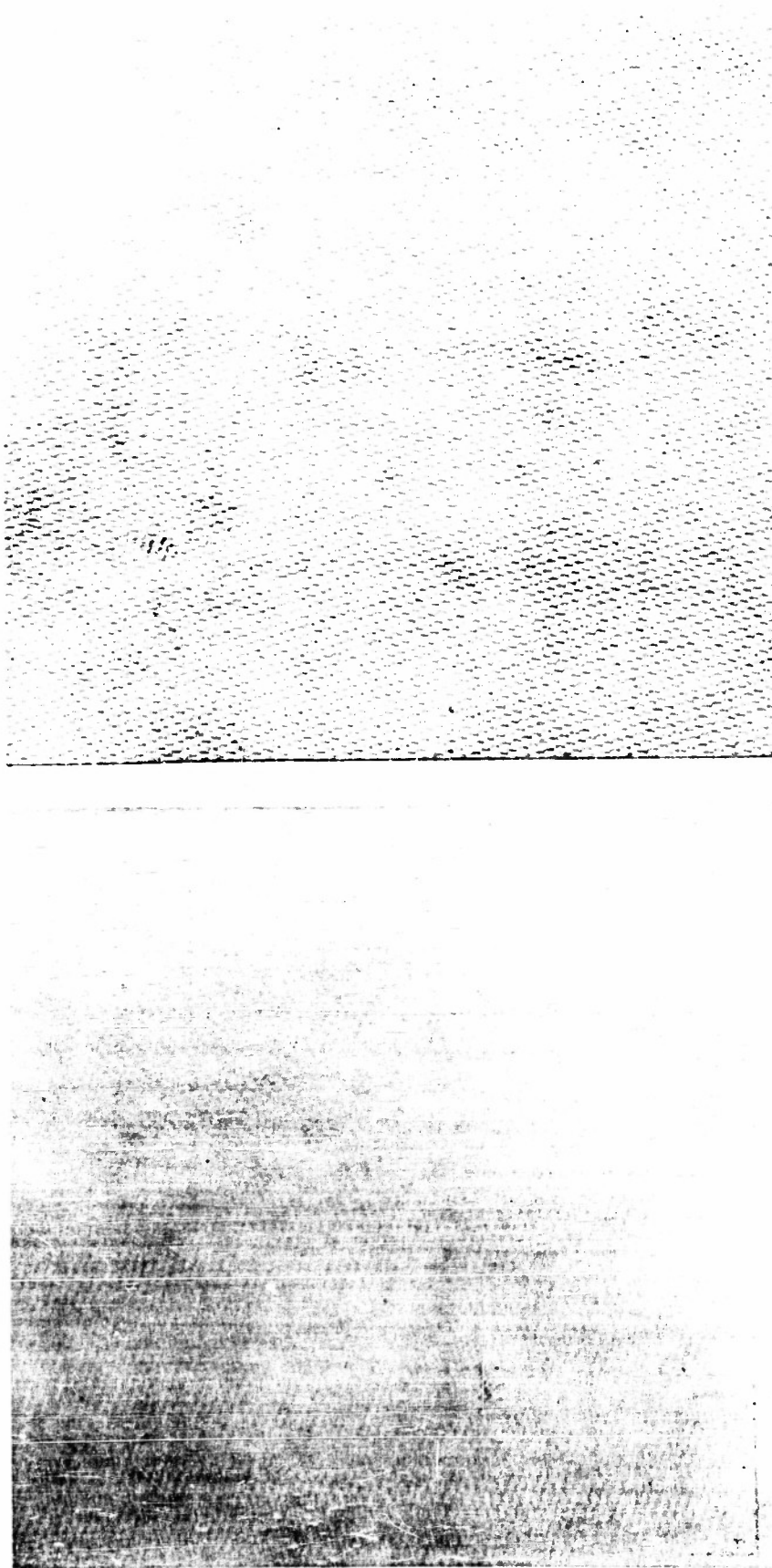


OPTIMUM QUALITY LAMINATE

"WHITE" LAMINATE

FIG. 16 "WHITE" LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

"WHITE" LAMINATE

FIG. 17 "WHITE" LAMINATE

PHOTO BY REFLECTED LIGHT

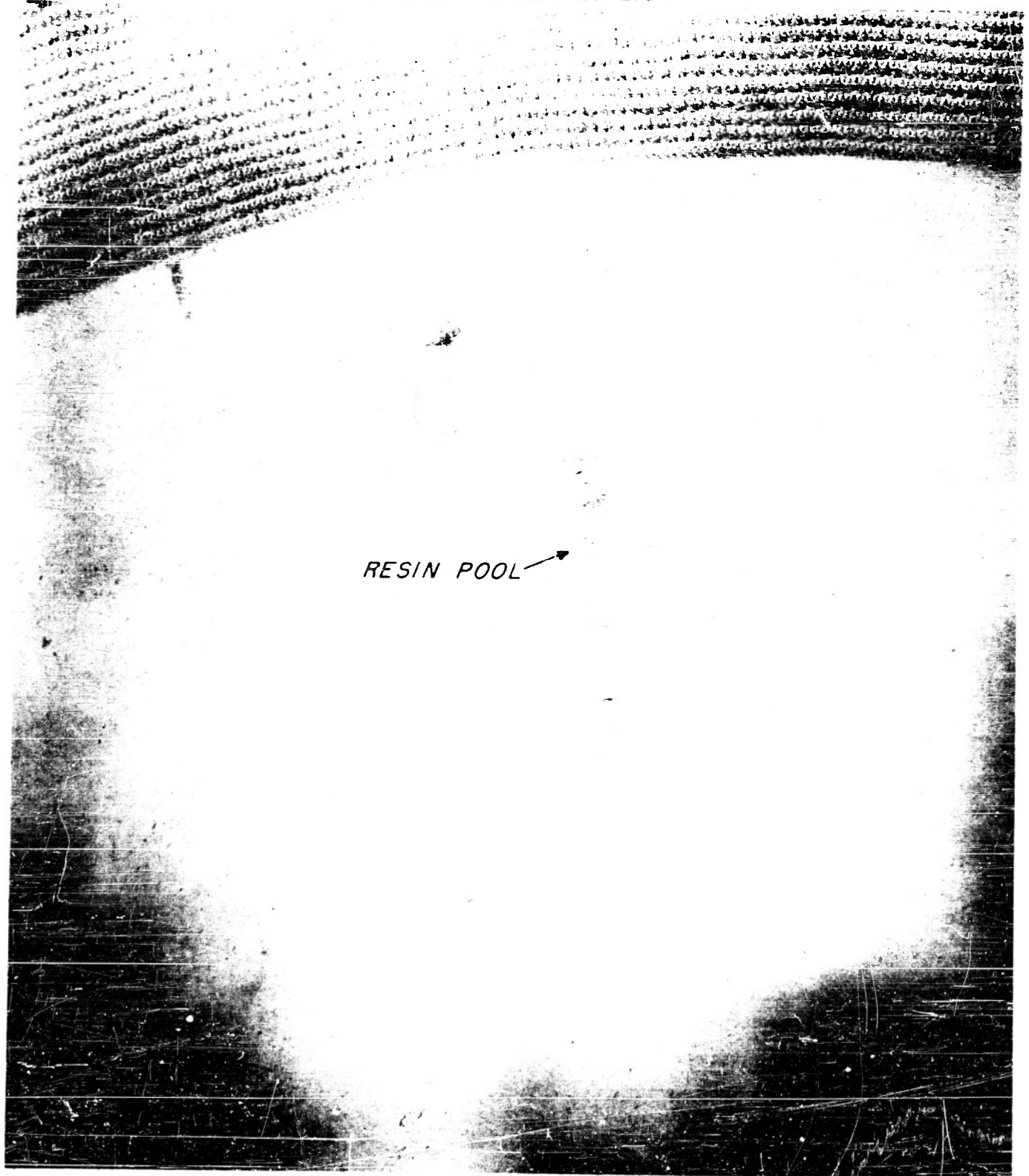
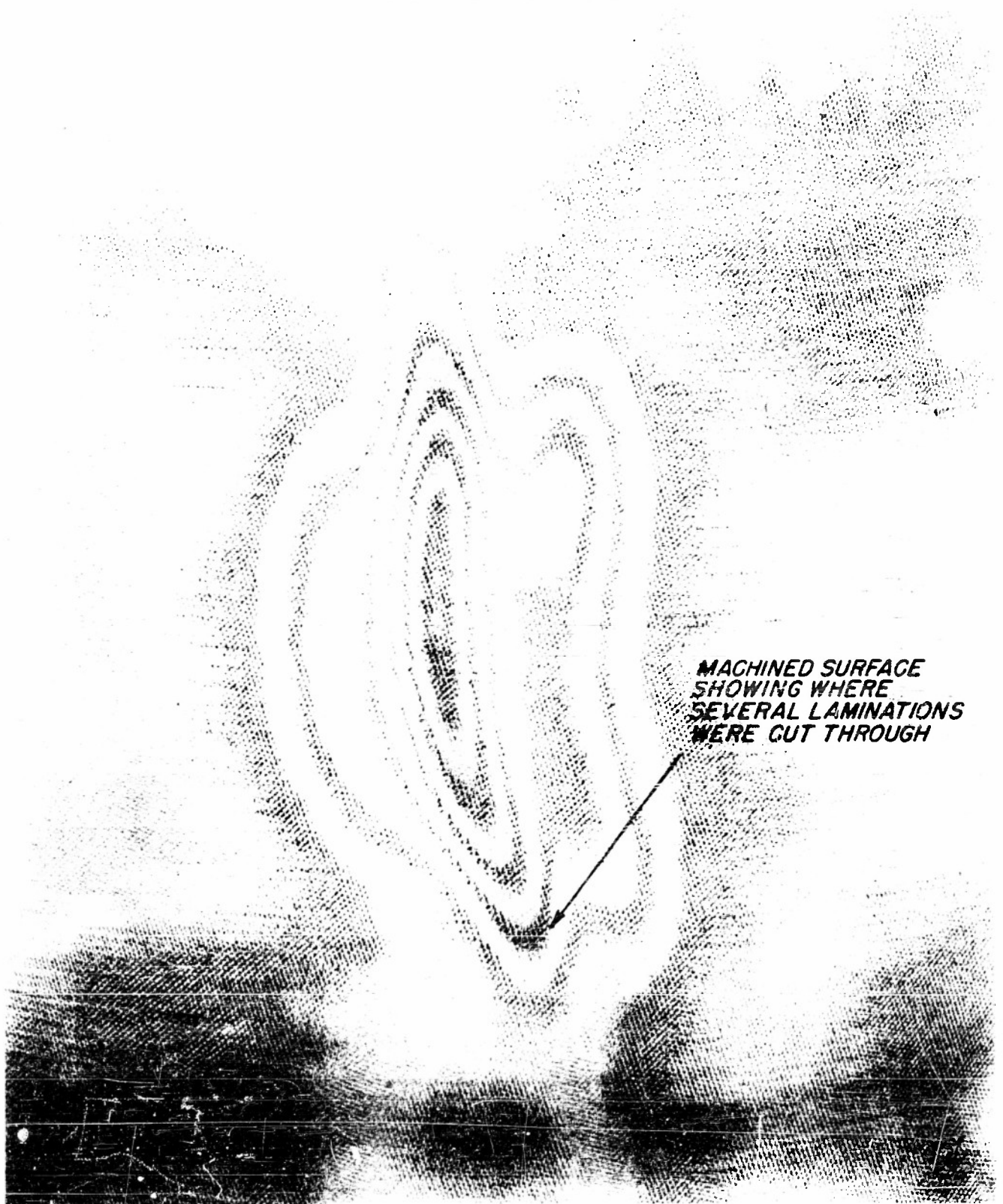


FIG. 18 RESIN POOL

PHOTO BY REFLECTED LIGHT



**MACHINED SURFACE
SHOWING WHERE
SEVERAL LAMINATIONS
WERE CUT THROUGH**

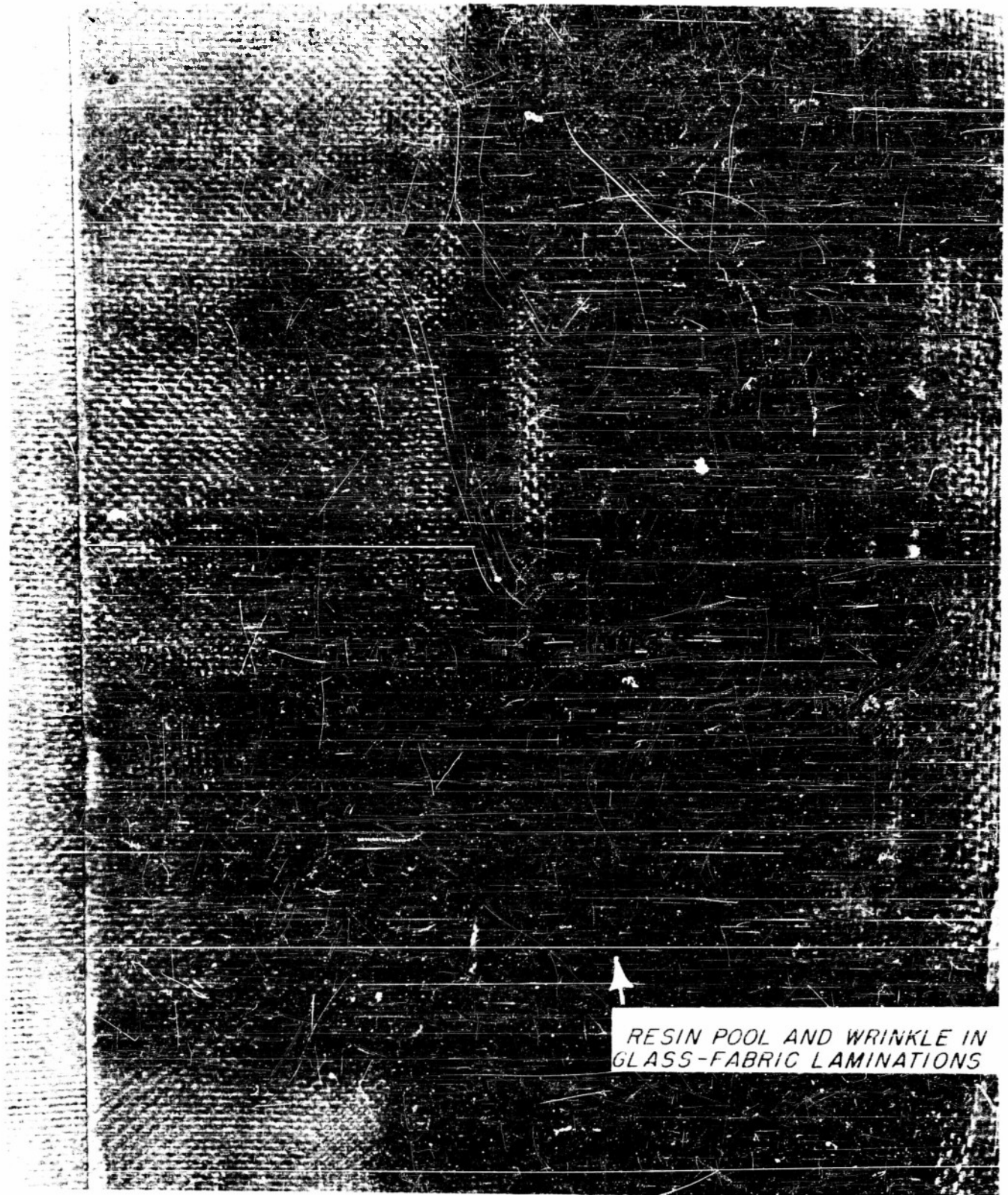
FIG.19 MACHINED SURFACE OF LAMINATE

PHOTO BY TRANSMITTED LIGHT



FIG. 20 REINFORCEMENT WRINKLE

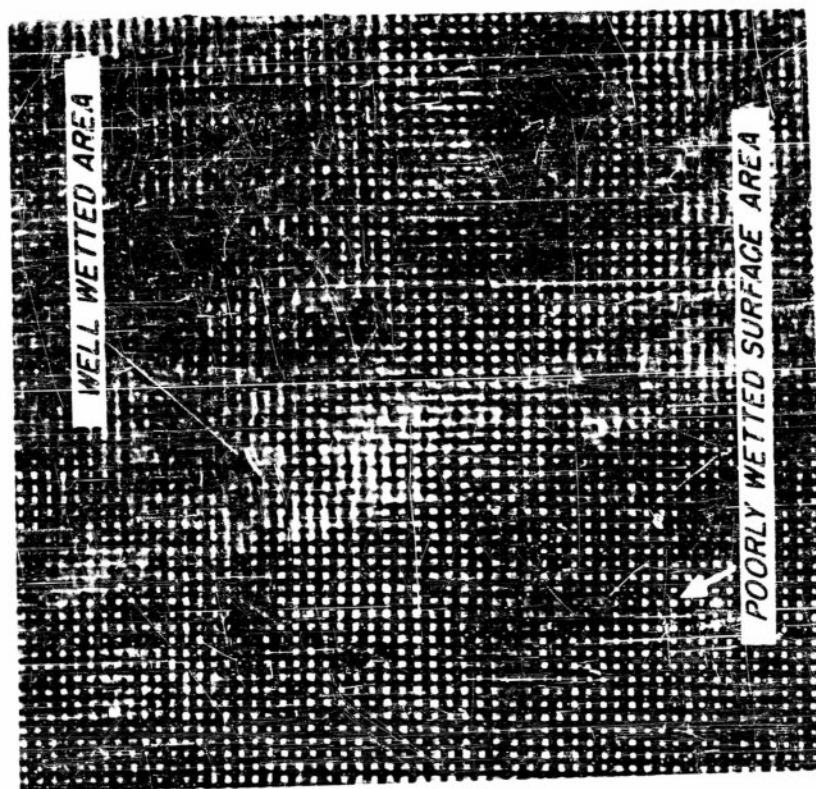
PHOTO BY REFLECTED LIGHT



RESIN POOL AND WRINKLE IN
GLASS-FABRIC LAMINATIONS

FIG. 21 REINFORCEMENT WRINKLE AND RESIN POOL

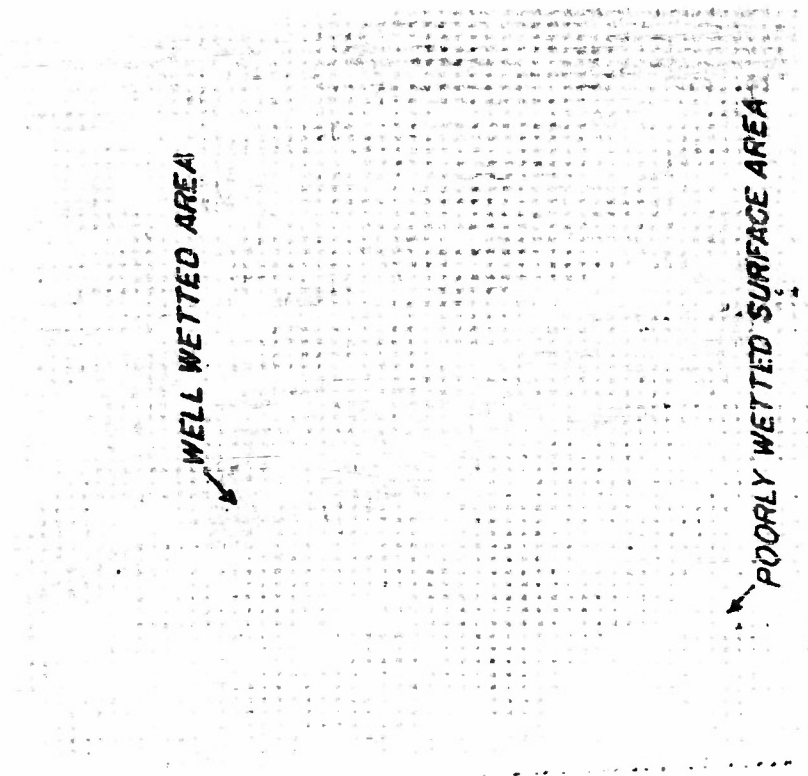
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 22 POORLY WETTED LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 23 POORLY WETTED LAMINATE

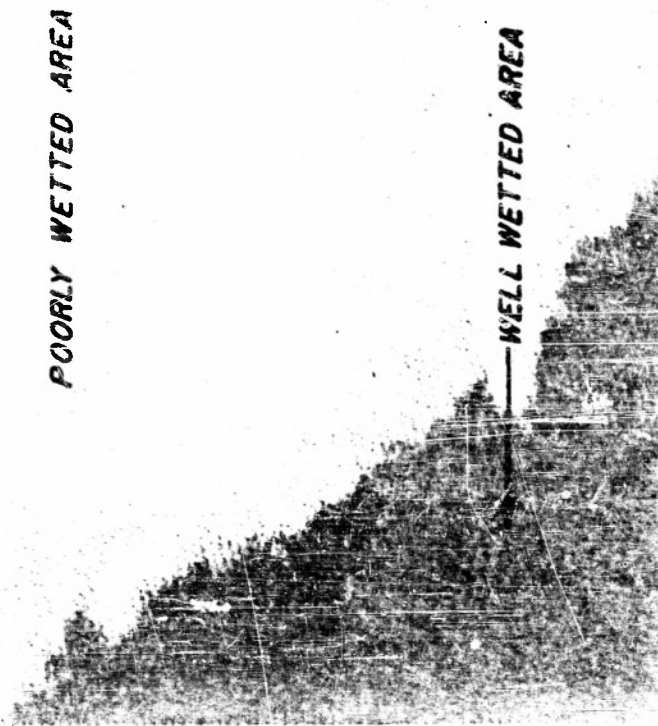
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 24 POORLY WETTED LAMINATE

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 25 POORLY WETTED LAMINATE

PHOTO BY TRANSMITTED LIGHT



POORLY WETTED
GLASS MAT
UNDER - PLY

OPTIMUM QUALITY LAMINATE

FIG.26 POORLY WETTED UNDER-PLIES IN LAMINATE

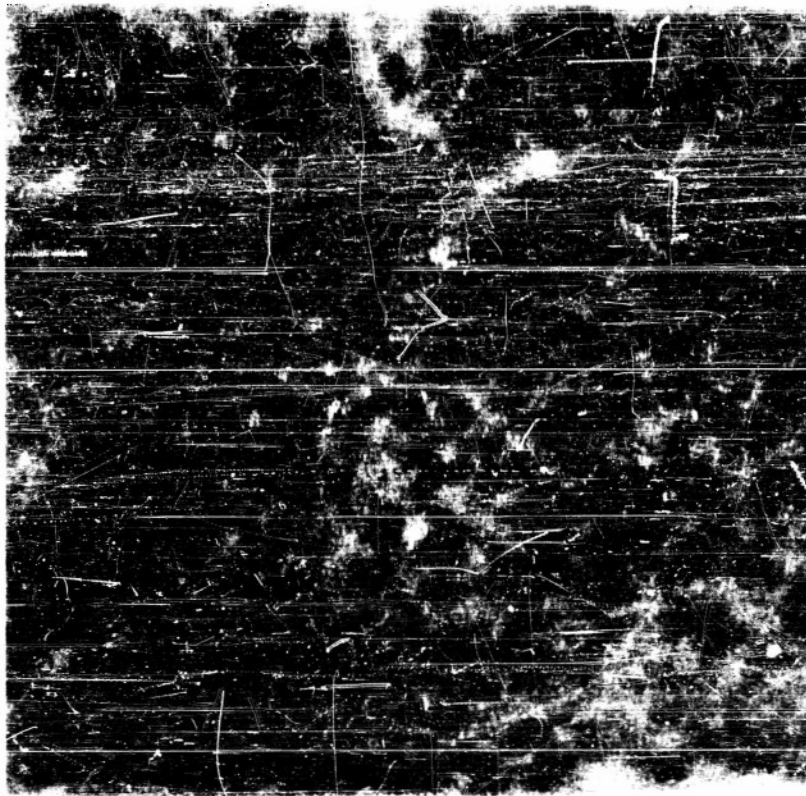
PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 27 POORLY WETTED UNDER - PLIES IN LAMINATE

PHOTO BY REFLECTED LIGHT

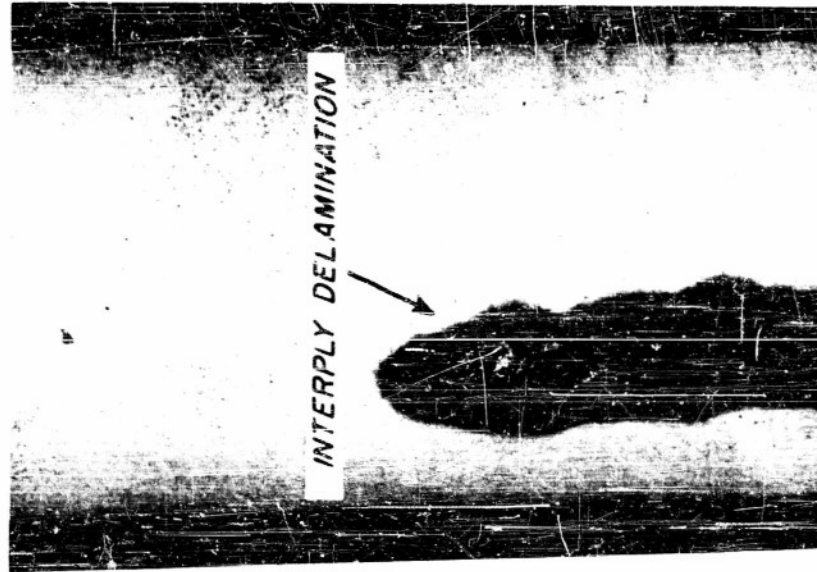


OPTIMUM QUALITY LAMINATE

POORLY WETTED GLASS MAT UNDER-PLY

FIG. 28 POORLY WETTED UNDER-PLIES IN LAMINATE

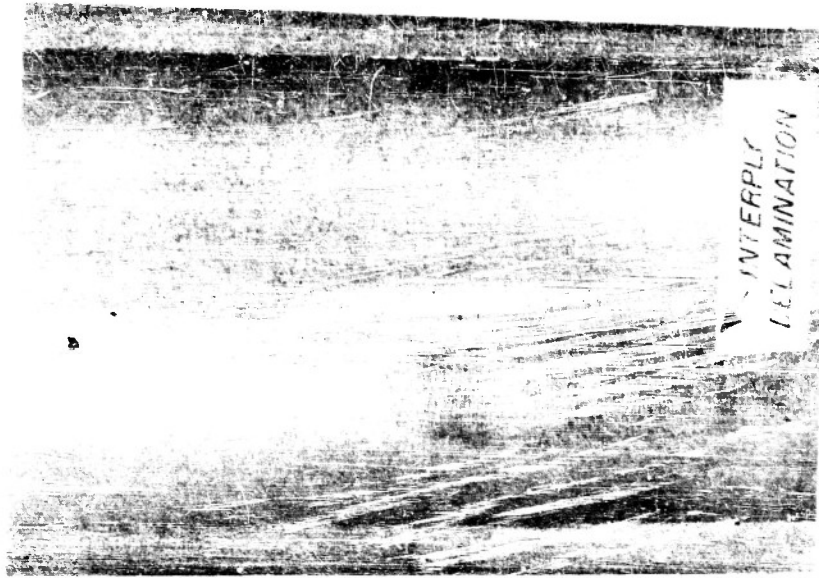
PHOTO BY TRANSMITTED LIGHT



OPTIMUM QUALITY LAMINATE

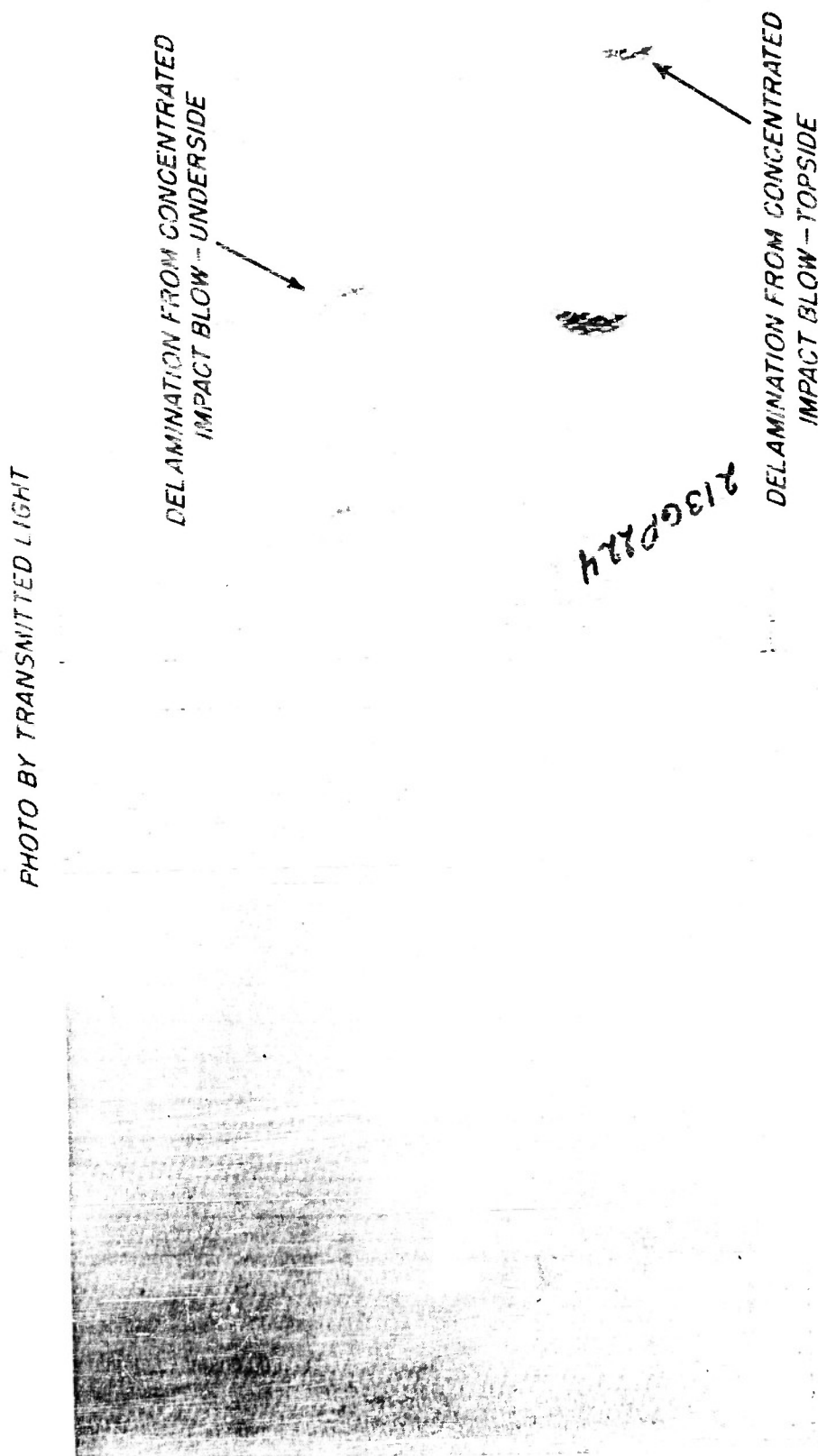
FIG. 29 INTERPLY DELAMINATION

PHOTO BY REFLECTED LIGHT



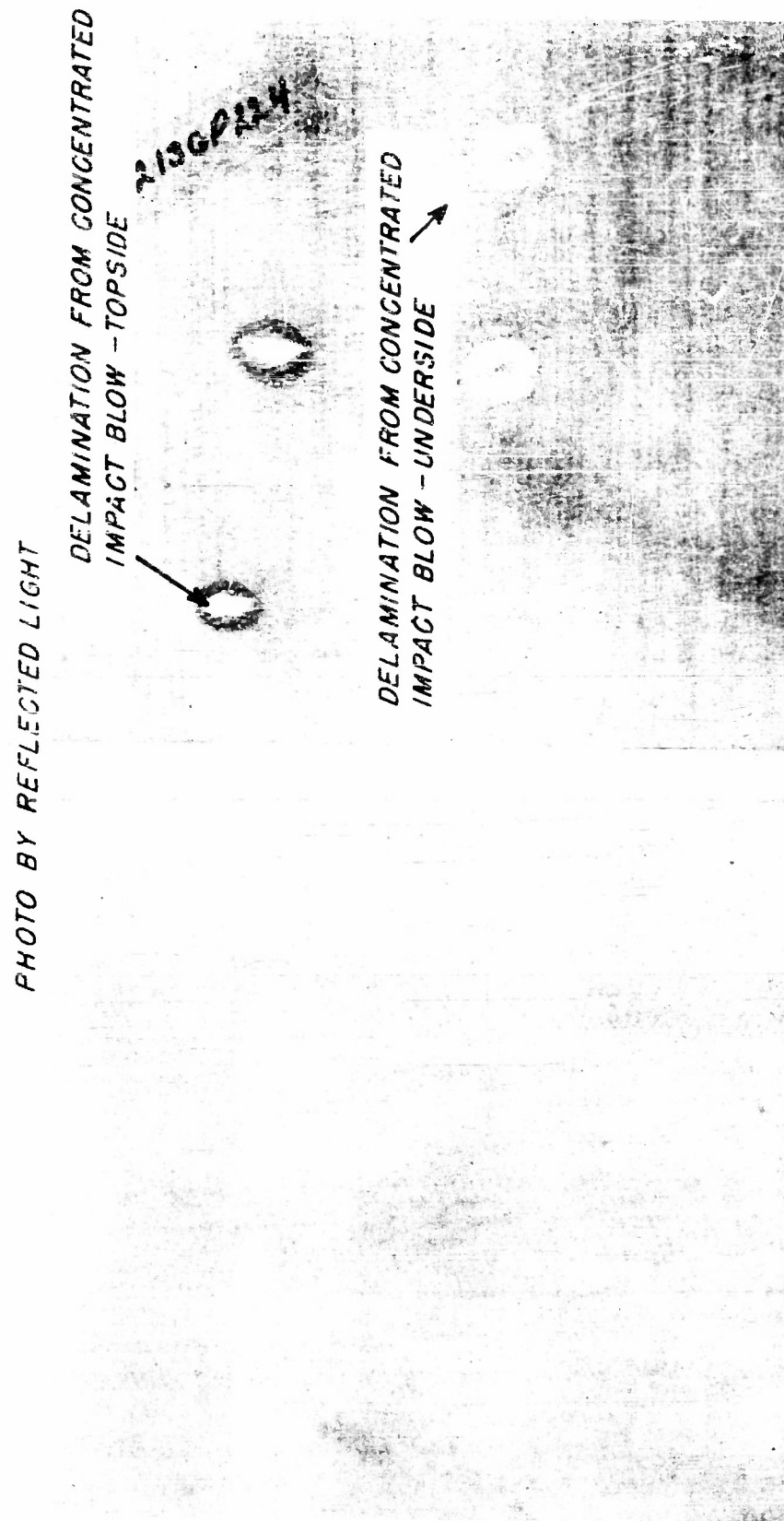
OPTIMUM QUALITY LAMINATE

FIG. 30 INTERPLY DELAMINATION



OPTIMUM QUALITY LAMINATE

FIG. 31 IMPACT DELAMINATIONS



OPTIMUM QUALITY LAMINATE

FIG.32 IMPACT DELAMINATIONS

PHOTO BY REFLECTED LIGHT



FIG. 33 PATCHES

PHOTO BY REFLECTED LIGHT

← SURFACE SCRATCH

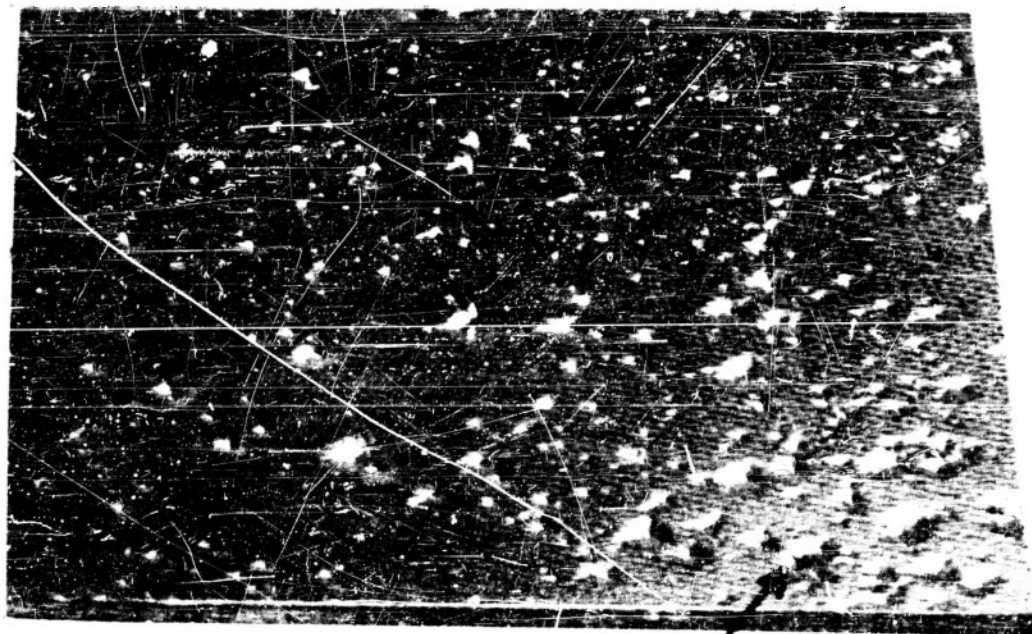
OPTIMUM QUALITY LAMINATE

SURFACE UNEVENNESS

FIG.34 SURFACE UNEVENNESS

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PHOTO BY REFLECTED LIGHT



SURFACE PITS

FIG.35 SURFACE PITS

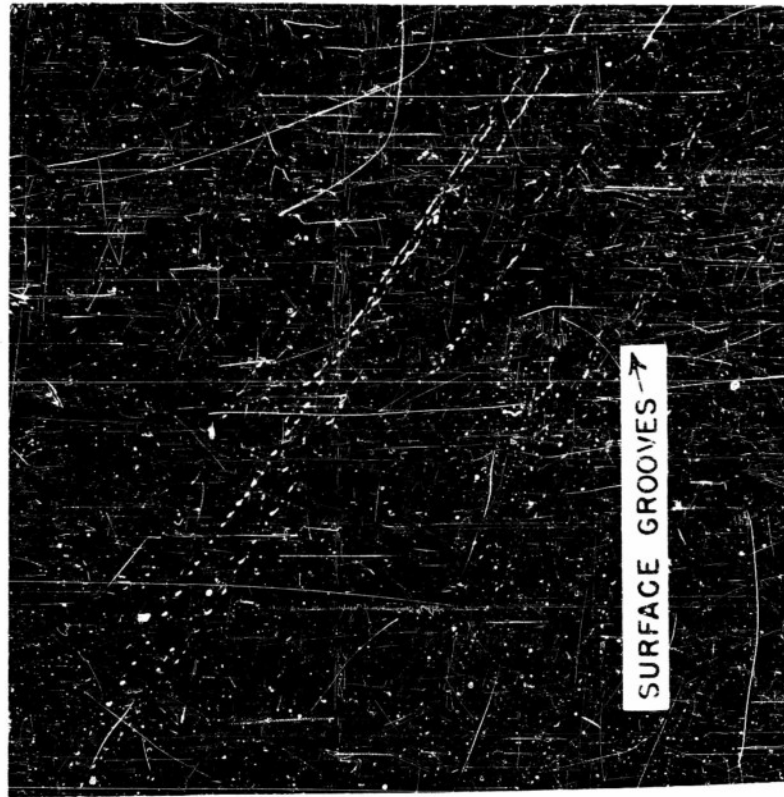
PHOTO BY REFLECTED LIGHT

SEVERE SURFACE PIT



FIG. 36 SURFACE PITS

PHOTO BY REFLECTED LIGHT



OPTIMUM QUALITY LAMINATE

FIG. 37 SURFACE GROOVES